



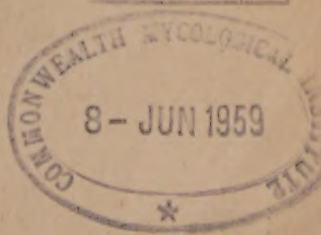
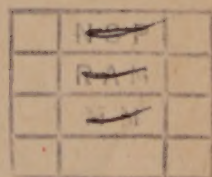
COMMITTEE OF THE PRIVY COUNCIL FOR
AGRICULTURAL RESEARCH

REPORT OF THE
AGRICULTURAL RESEARCH COUNCIL
FOR THE YEAR 1957-58

*Presented to Parliament by the Lord President of the Council
by Command of Her Majesty
June 1959*

LONDON
HER MAJESTY'S STATIONERY OFFICE
EIGHT SHILLINGS NET

Cmnd. 750





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FOUR SMITHFIELD WAY

AGRICULTURAL RESEARCH COUNCIL

At Date of Report

His Grace The Duke of Northumberland, K.G. (Chairman)
David Lowe, Esq., C.B.E. (Deputy Chairman)
J. D. Alston, Esq., J.P.
Professor T. A. Bennet-Clark, M.A., Ph.D., F.R.S.
Professor E. G. Cox, T.D., D.Sc., F.Inst.P., F.R.I.C., F.R.S.
R. E. Glover, Esq., M.A., D.Sc., F.R.C.V.S.
J. Hensley, Esq., M.A.
Professor J. W. Howie, M.D., M.R.C.P., F.R.F.P.S.
Elwyn Jones, Esq., O.B.E., J.P.
Professor Sir Hans A. Krebs, M.A., M.D., D.Sc., F.R.C.P., F.R.S.
Professor K. Mather, C.B.E., D.Sc., Ph.D., F.R.S.
Professor P. B. Medawar, C.B.E., M.A., D.Sc., F.L.S., F.R.S.
F. Rayns, Esq., C.B.E., M.A.
J. N. Ritchie, Esq., C.B., B.Sc., F.R.C.V.S., D.V.S.M., F.R.S.E.
Professor H. G. Sanders, M.A., Ph.D.
W. H. Senior, Esq., B.Sc., (Agric.), M.Sc. F.R.S.E.
Professor S. J. Watson, C.B.E., D.Sc., F.R.I.C., F.R.S.E.
Professor Sir Solly Zuckerman, C.B., M.A., M.D., D.Sc., F.R.S.

Sir William K. Slater, K.B.E., D.Sc., F.R.I.C., F.R.S. (Secretary)
W. G. Alexander, Esq., C.B.E., M.A. (Deputy Secretary)

SENIOR STAFF AT HEADQUARTERS

Secretary to the Council:

Sir William K. Slater, K.B.E., D.Sc., F.R.I.C., F.R.S.

Deputy Secretary:

W. G. Alexander, C.B.E., M.A.

Assistant Secretaries:

W. Ness

P. A. C. Thorne

A. J. D. Woods, C.B.E., B.A.

Scientific Assistants to the Secretary:

E. E. Cheesman, D.Sc., A.R.C.S.

G. G. Samuel, M.Sc.

R. Scarisbrick, M.A., Ph.D., M.R.C.V.S., [¶]A.R.I.C.

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THE REPORT OF THE COMMITTEE OF PRIVY COUNCIL FOR AGRICULTURAL RESEARCH FOR THE YEAR 1957-58

TO THE QUEEN'S MOST EXCELLENT MAJESTY,
MAY IT PLEASE YOUR MAJESTY,

We, the Lords of the Committee for Agricultural Research of Your Majesty's Privy Council, humbly submit to Your Majesty a Report of our proceedings during the year from 1st April, 1957 to 31st March, 1958.

During the financial year 1957-58, Parliament provided a total of £3,862,000 as a grant-in-aid of the Agricultural Research Fund. This total was based on estimated current expenditure of £3,600,000 gross, receipts of £258,000 and capital expenditure of £520,000 on buildings and special apparatus.

The estimates of the Agricultural Research Council for that financial year were met as in the previous year by our provisional allocation of funds under the following heads:

For administration, including the expenses of the Council and of the administrative offices and staff;

For the current expenditure, including salaries and wages of the staffs of the Council's Institutes and Units;

For grants for current expenditure, including salaries and wages, to State-aided research institutes in England and Wales;

For grants for special research schemes;

For Training Awards, Fellowships and visits abroad;

For capital expenditure, mainly on new buildings, for the Council's research institutes and units and for the State-aided research institutes.

During the year under report five new members were appointed to the Agricultural Research Council. After the required consultation with that Council and with the President of the Royal Society, we appointed James William Howie, M.D., M.R.C.P. (Gardiner Professor of Bacteriology in the University of Glasgow); Thomas Archibald Bennet-Clark, M.A., Ph.D., F.R.S. (Professor of Botany at King's College in the University of London) and Ernest Gordon Cox, T.D., D.Sc., F.Inst.P., F.R.I.C., F.R.S. (Professor of Inorganic and Structural Chemistry in the University of Leeds). These appointments filled the vacancies created by the retirement of Professor J. S. Young, M.C., M.A., B.Sc., M.D., Professor E. J. Maskell, M.A., Ph.D., F.R.S. and Professor L. P. Pugh, M.A., B.Sc., F.R.C.V.S. Other vacancies were filled by the appointment of Mr. J. D. Alston, J.P. (upon the retirement of Sir James Turner, B.Sc., LL.D. after ten years' service as a member of the Council) and of Mr. Elwyn Jones, O.B.E., J.P. We also appointed for a second term of five years Peter Brian Medawar, C.B.E., M.A., D.Sc., F.L.S., F.R.S. (Jodrell Professor of Zoology and Comparative Anatomy in the University College of London). Mr. J. Hensley succeeded Mr. W. C. Tame as a representative on the Council of the Ministry of Agriculture, Fisheries and Food. Mr. David Lowe, C.B.E., succeeded Professor S. J. Watson, D.Sc., F.R.I.C., F.R.S.E. as Deputy Chairman of the Council.

On the 30th June, 1958 the Lord Rothschild, G.M., M.A., Sc.D., Ph.D., F.L.S., F.R.S. relinquished the Chairmanship of the Council, an office which he had held with great distinction for ten years. He has been succeeded by His Grace the Duke of Northumberland.

By an Order in Council, dated 14th March, 1958, a Supplemental Charter was granted. This prescribed a simplified procedure for alterations or amendments to the Original Charter of 1931 as amended by subsequent Supplemental Charters and provided that honoraria should not be paid to members of the Agricultural Research Council who were also members of the House of Commons.

We now beg to submit the Report which we have received from the Agricultural Research Council describing the progress of their work during the twelve months ending on the 31st March, 1958.

The Council has remained in close touch with the scientists in other parts of the Commonwealth, the United States of America and other countries. It has continued to work closely with the various Departments at home, including the Ministry of Agriculture, Fisheries and Food, the Department of Agriculture for Scotland and, on matters affecting colonial agriculture, the Colonial Office. It has also kept in consultation with the Medical Research Council and the Department of Scientific and Industrial Research on questions of common interest.

On behalf of the Lords of the Committee for Agricultural Research
Your Majesty's Privy Council.

HAILSHAM,

Lord President of the Council.

W. K. SLATER,

*Secretary to the Committee of Privy Council
for Agricultural Research.*

16th February, 1959.

THE REPORT OF THE AGRICULTURAL RESEARCH COUNCIL FOR THE YEAR 1957-58

To the Lords of the Committee of Privy Council for Agricultural Research.
May it please your Lordships,

The Agricultural Research Council beg leave to submit the following Report upon their proceedings during the period from 1st April, 1957 to 31st March, 1958.

INTRODUCTION

CO-ORDINATION OF RESEARCH EFFORT

During the year the Council has continued its efforts to achieve the best possible co-ordination between the work carried on under its guidance and the needs of the industry. The Joint Committee of the Council together with the Improvement Councils for England and Wales and for Scotland, whose work was described in the First Annual Report, has made surveys of the needs of further commodities and allotted priorities to the individual problems, after extensive consultation with the appropriate bodies representing the industry. These assessments of priorities have been examined by the Council in relation to the work in progress.

In general it has been found that the programmes of work set out by the institutes have been in close agreement with the assessed needs of the industry. Where there are obvious gaps the cause is almost always due to a shortage of adequately trained staff to undertake the work. Thus the surveys of the problems involved in pig and poultry farming have shown that an increased effort is needed if these rapidly expanding branches of agriculture are to be fully served. It is, however, just in these two branches of research where there is the greatest shortage of trained men. The Council has for some years been encouraging recruitment in these fields, but the pull of the older and more firmly established branches of agricultural research has made this difficult. The results of the Council's efforts, supported now by the Pig Development Authority and the Egg Marketing Board, are however, beginning to have an effect and there is a reasonable prospect of more men devoting themselves to this important work.

FUTURE OF FOOD RESEARCH

Meat production presents another series of problems urgently in need of more work. These fall into two parts: one the breeding, rearing and feeding of cattle, sheep and pigs and the other the slaughter, handling and processing of the carcasses. These two groups of problems are obviously closely interrelated; the producer of the live animal can only measure the results of his work in terms of the final carcass; equally the scientist investigating the meat aspects of the work must know the history of the animal, the carcass of which he is studying. Under the existing arrangements the first group of problems is the responsibility of the Council, whilst the second is that of the Department of Scientific and Industrial Research. Whilst there has been useful co-operation between the scientists working for the two Councils, it is clearly an unsatisfactory arrangement that the two parts of what is in effect one research problem should be administered by different organisations.

The same division of effort is to be found in other branches of food production, e.g. fruit growing and storage, vegetable growing and the methods of handling, packing and distribution.

These difficulties were recognised by the Department of Scientific and Industrial Research in 1956 and the Department proposed to the Council that it should take over certain of the laboratories dealing with food research. Whilst welcoming the proposal that research on the production of food should be integrated with that on its processing and storage, the Council considered that before any step was taken a careful examination of the present and future needs of the food side of the industry should be made. The Ministry of Agriculture, Fisheries and Food was asked to prepare an estimate of these needs and this was examined by a Sub-Committee of Council members in relation to the facilities already available to the Council for the study of dairy products, fruit juice and cider, and to a lesser extent for the storage and handling of fruit and vegetables, in order to estimate what further facilities would be needed and how far these would be met by the proposed transfer of laboratories from the D.S.I.R. After careful consideration, the Council concluded that to fulfil the obligations it would be undertaking to the Ministry of Agriculture, Fisheries and Food it would be essential to provide for the transfer of another laboratory, in addition to those originally proposed by the D.S.I.R.

Negotiations with the D.S.I.R. have been going on throughout the year under review and agreement has now been reached for the transfer to the Council of the Low Temperature Research Station, the Ditton Laboratory and the Pest Infestation Laboratory.

While the Council was examining the question of the transfer of these laboratories, the Meat Research Committee of the M.A.F.F. was considering how far the demand for a meat research institute was justified. They were helped in this examination by the loan of the services of Dr. Vickery, the leading authority on meat research in Australia, and on the basis of his report the Committee recommend the establishment of a meat research centre. It will be one of the Council's first tasks, when the responsibility for food research is transferred, to study how best this recommendation can be implemented.

FARM BUILDINGS RESEARCH

The Farm Buildings Research Committee, set up by the Council after it had assumed responsibility for this branch of research in November 1956, decided that before any major research activity could be started it would be necessary to make a careful study of what was already known and to try to ascertain the most pressing needs of agriculture.

The Special Survey Department of the National Institute of Agricultural Engineering was asked to carry out this preliminary work. Apart from diverting to it some of the time of its existing staff, the Department was given the services of a special unit created for the purpose and consisting of three additional staff; it was also able to draw upon the resources of the library and abstracting services at the Institute.

Research on farm buildings falls into three major parts. The first deals with the requirements of the animals, crops, supplies and equipment to be housed; the second with the structure of the building to meet these requirements; and the third with the planning of the individual buildings and groups of buildings to provide the most economic layout.

The literature to be examined is extremely widely dispersed throughout scientific and technical journals; much of it is of doubtful value. As a first step experts in the different fields were asked by the Council to prepare summaries of the existing knowledge and to indicate where further research was required.

Subjects reviewed in this way included the environmental conditions required for optimum production for cattle, pigs and poultry, the protection of buildings against vermin, and the conditions required for the handling and storage of grain. At the same time a full examination of the literature dealing specifically with farm buildings was begun by the unit at the N.I.A.E., the preliminary abstracting to be completed by the end of 1958 and the critical appraisal of these abstracts to be finished by the Spring of 1959.

The inquiry into the needs of the industry has taken the form of a survey of existing buildings in relation to the farming enterprises they serve; it is hoped in this way to obtain a general picture of the existing buildings in Great Britain, their age, their suitability to their present use, and hence the probable demand for new buildings. It is also hoped to obtain from the M.A.F.F. statistical information on the nature of the approved applications under the Farm Improvement Scheme, which will be used to supplement that obtained from the survey.

The Building Research Station of the D.S.I.R. has agreed to assist as far as possible by providing as required studies of the structure of farm buildings, and the Land Services of the Ministry of Agriculture, Fisheries and Food and the Department of Agriculture for Scotland are also co-operating in the work. The Building Research Station has already undertaken a comprehensive examination of the climatic conditions in a number of types of existing piggeries, the results of which are now ready for publication.

The planning and layout of farm buildings is not a subject which easily lends itself to research. Each set of buildings, and to some extent each individual building, calls for special treatment. All that the research worker can do is to provide the information from which standard types can be evolved; often this will mean little more than selecting the best from existing types found either in this country or overseas. Where no satisfactory existing type is found, variants or entirely new designs will have to be evolved.

Whilst the Council is not responsible for development as opposed to research, it is clear that it will be impossible to test in full the conclusions reached by the research worker without controlled trials of buildings incorporating new features, on commercial holdings. This aspect of the work will therefore have to be carefully considered by the Farm Buildings Research Committee.

The Council, however, is not content merely to await the results of these enquiries. Wherever a suitable opportunity occurs to start work which is clearly needed the Council is prepared—within the limits of its resources—to make the funds available. A number of these projects will be found in the list of research grants and others have been, or will be, started as soon as possible in existing research institutes.

ASSUMPTION OF RESPONSIBILITY FOR MONITORING BIOLOGICAL MATERIALS

For a number of years research on the effects of radiation on biological materials has been carried out by the Agricultural Research Council (on animals, plants and soil) and the Medical Research Council (on the human body). The non-medical aspects of this research have been supervised by a Joint A.R.C./M.R.C./D.C. Committee under the chairmanship of Lord Rothschild. The monitoring of the level of fall-out however and of its absorption by various materials was for several years undertaken by the Atomic Energy Research Establishment at Harwell. In the Summer of 1957 it was decided to expand the monitoring effort and to place it under the detailed supervision of an expert Sub-Committee of the Joint Committee. The Agricultural Research Council was charged with the responsibility for monitoring radioactive fall-out in soil, herbage, farm animals, milk and other foodstuffs (Harwell retaining the responsibility for monitoring air,

water and human bone). At the time the Council had neither the facilities nor the staff to undertake this major task. The Atomic Energy Authority, however, agreed to undertake part of the analytical work and to lend a building at Wantage to act as a temporary laboratory. Staff was recruited as quickly as possible and the Council was able to take over in January, 1958 the arrangements for the collection and preparation of the samples. A permanent site has now been obtained a few miles from Wantage and a laboratory is to be built specially for this purpose. A comprehensive system of sampling has been introduced which is designed to show the general level throughout the country of strontium 90 present in foodstuffs and other biological materials and at the same time to check on the levels in areas where the exposure of the population may be higher than average owing to high rainfall and other local conditions.

The Council has undertaken to publish the results of this monitoring annually, and should any marked upward change occur at any time in the levels to inform the Medical Research Council and the Ministry of Agriculture, Fisheries and Food immediately.

As a result of the assumption of responsibility for monitoring radioactive fall-out, the Council's staff was asked to help in ascertaining the extent of radioactive contamination resulting from the Windscale accident.

FINANCING RESEARCH IN THE UNIVERSITIES

During the year the Council gave consideration to the problem of financing research in the Universities. It has become increasingly obvious that many science departments in the Universities have insufficient funds available to meet the basic research needs of the teaching staffs. In particular, the Council was concerned about those, such as the veterinary departments, where there were heavy demands resulting from the cost of keeping farm animals. The Council has always regarded its own funds for University research as being available to help promising investigations over short terms by the provision of assistants, either scientific or technical, special apparatus and materials. Requests were, however, being received in increasing numbers for long term support for the normal research activities of University departments. It was clear that if the Council met these its funds would be permanently committed and when any new and promising development occurred it would be unable to help. The Council was therefore very pleased at the request of the Advisory Council on Scientific Policy, to join with the other Research Councils, the Royal Society and the University Grants Committee in discussions on the financing of University research. As a result of the recommendations made, the Council is hoping in the financial year 1959-60 to meet at least some of the special requirements of rapidly expanding University departments. Further discussions will be necessary and are to take place before a fully effective scheme can be evolved.

VETERINARY THERAPEUTIC TESTING SCHEME

The Council decided in May, 1957 to set up a Veterinary Therapeutic Testing Board similar in function to that of the Medical Research Council for testing drugs for use in human medicine. There has been a very disappointing response. At the time the Board was set up evidence was presented that there was a real need for such a body with the power to carry out tests. In spite of the wide publicity given to these arrangements there have been very few applications for the Board to consider and none which seemed to be worthy of a full scale examination.

SPECIAL SUBJECTS REFERRED TO THE COUNCIL

During the year two questions have been referred to the Council by the Ministry of Agriculture, Fisheries and Food. The first concerns drift of herbicidal sprays and the possible damage to other crops. The Council advised the

Ministry on the present position and agreed to encourage further research. Special research grants were accordingly made to the University of Nottingham and the National Vegetable Research Station for studies on certain aspects of this problem.

The second question was whether it is safe to administer to cattle, whether by feeding or implantation, synthetic oestrogens such as stilboestrol and hexoestrol. Evidence both from the U.S.A. and from experiments carried out in this country (e.g. at the Rowett Research Institute and at the University of Nottingham) has shown that significant increases in weight gain and improvement in the efficiency of food conversion can be obtained by either feeding or implanting these substances in suitable doses. Because, however, there was apprehension lest the excretion of these chemically stable substances might lead to their accumulation in the soils and on the pastures with highly adverse results to breeding stock, the Council undertook to institute experiments at several centres to ascertain whether these synthetic oestrogens would readily decompose in the soil as a result of the action of soil micro-organisms. The indications are that they will be so decomposed but further experiments are necessary to confirm the preliminary findings. Attention is also being given to the question of the composition of the body weight gains resulting from treatment and the effects of the treatment on the quality of the carcase.

LORD ROTHSCHILD'S RETIREMENT

The year under review was the last full year in which Lord Rothschild was Chairman of the Council. The Council wish to place on record their great indebtedness to him for his guidance during the last ten years. Lord Rothschild has greatly enhanced the stature of the Council by his insistence on the highest standards in scientific work and in the administration of its affairs.

ADMINISTRATION AND FINANCE

1957-58

ROYAL VISIT

East Malling Research Station was honoured by a visit from H.R.H. Prince Philip, Duke of Edinburgh, on 30th April 1957.

STAFF

At the close of the year under report there were 3,923 members of staff employed at the agricultural research institutes. Of this number 812 were in the Scientific Officer class, 556 in the Experimental Officer class and 728 in the Assistant (Scientific) class. The remainder were mainly in the executive, clerical and industrial classes. The number employed in the Council's Secretariat was 75.

CHANGES IN DIRECTORSHIPS

Professor T. Wallace retired from the Directorship of Long Ashton Research Station on 30th September, 1957 on reaching the age limit; he remains Director of the Council's Unit of Plant Nutrition (Micro-Nutrients) until September, 1959. Dr. H. G. H. Kearns has succeeded Professor Wallace as Director of the Station and has also been elected to the Chair of Agricultural and Horticultural Science in the University of Bristol.

Dr. R. Scott Russell was appointed on 1st November, 1957 to be Director of the A.R.C. Radiobiological Laboratory.

Dr. D. N. McArthur retired from the Directorship of the Macaulay Institute for Soil Research in March, 1958 and Dr. A. B. Stewart, Strathcona-Fordyce Professor of Agriculture in Aberdeen University, has been appointed to the Directorship from 1st October, 1958.

Mr. M. S. Pease retired from the Directorship of the Poultry Genetics Station in September, 1957.

OTHER APPOINTMENTS

Dr. R. C. Campbell, head of the A.R.C. Statistics Group, Cambridge, was appointed Lecturer in Statistics in the Department of Agriculture, University of Cambridge, on 1st October, 1957: he continues, however, to supervise the work of the Statistics Group.

In June, 1957 Professor J. E. Nichols, Professor of Agriculture (Animal Husbandry) in the University College of Wales, Aberystwyth, was appointed A.R.C. Adviser on Sheep Research.

HONOURS AND AWARDS

During the year the following honours were conferred by Her Majesty the Queen:—

Knight Bachelor	...	Professor Hans Krebs	} Members of Council
C.B.E.	...	Professor P. B. Medawar	
C.B.E.	...	Dr. D. P. Cuthbertson, Director of the Rowett Research Institute	

Sir William Slater, Secretary of the Council, was elected a Fellow of the Royal Society and Professor F. G. Gregory, Director of the Research Institute of Plant Physiology, was awarded the Society's Royal Medal.

Mr. J. N. Ritchie, a member of the Council, Dr. J. W. Gregor, Director of the Scottish Plant Breeding Station and Sir Rudolph Peters, Dr. A. McDiarmid and Dr. R. Osborne, members of the Council's staff, were elected Fellows of the Royal Society of Edinburgh.

The Royal Agricultural Society of England awarded its Research Medal for 1957 to Dr. A. Walton, Deputy Director of the Council's Unit of Reproductive Physiology and Biochemistry.

LECTURES

Sir William Slater addressed the seventy-fifth Annual Congress of the British Veterinary Association, held at Cambridge, in August, 1957, his subject being "Studies of the normal animal in relation to disease".

VISITING GROUPS

The following institutes received Visiting Groups during the year:—

Animal Diseases Research Association
John Innes Horticultural Institution
Scottish Plant Breeding Station

SCIENTIFIC COMMITTEES

The Council and its Standing Committees have continued to be assisted by Committees and Conferences of scientists and agriculturists particularly interested in various fields of work. In November, 1957 the Veterinary Therapeutic Testing Board held its first meeting; this Board has been set up to administer a Scheme authorised by the Council, under which substances for use in the prevention, control or treatment of animal diseases can be submitted to an impartial test at the request of the manufacturer or of a veterinary professional organisation.

The Sub-Committees (on disease, housing and nutrition respectively) of the Technical Committee on Pig Research have been dissolved, having completed the tasks for which they had been appointed. It is expected that the Technical Committee will in future convene *ad hoc* conferences to consider research in progress, or required, on particular subjects.

During the year the Technical Committee on Special Crops was dissolved on the completion of its work. The Committee had been set up in 1946 when, as part of the post-war review of agricultural research, special attention was being given to the possibilities of establishing certain crops not normally grown in this country.

OVERSEAS LIAISON

Many visitors from abroad have been received by headquarters staff and the research centres. In co-operation with the Departments and other Councils arrangements were made for visits, under various international schemes, such as the Food and Agriculture Organisation, the Colombo Plan, the Baghdad Pact, the World Health Organisation and Yugoslav Technical Aid; by aid of scholarships and fellowships awarded by Commonwealth and foreign Governments, institutes, universities and foundations; and also under exchange schemes. Some 200 visitors spent periods of a month or more at agricultural research centres during the year.

Scientists from the agricultural research service went abroad during the year under the auspices of international organisations, Commonwealth and foreign Governments, foundations and exchange schemes for the purpose of investigating and advising upon overseas problems or in order to widen their own experience.

The Council also made grants to some 130 workers to enable them to visit research centres abroad or to take part in a number of international conferences. These included a conference at the Statistical Institute in Sweden and conferences held in Holland on potato virus diseases; in Germany on crop protection and nematology; and in France on nutrition, the use of radio isotopes in scientific research and on pure and applied chemistry.

Close liaison with agricultural research in Colonial and Commonwealth territories was maintained. Sir William Slater, as Secretary of the Council, continued to be Chairman of the Committee for Colonial Agriculture, Animal Health and Forestry Research. Mr. W. G. Alexander, Deputy Secretary, was appointed as United Kingdom representative on the Executive Council of the Commonwealth Agricultural Bureaux and Mr. W. Ness, Assistant Secretary, continued to act as the Bureaux' Liaison Officer for the United Kingdom. Dr. E. E. Cheesman, one of the Scientific Assistants to the Secretary, again served as the United Kingdom delegate to the Sub-Commission on Agricultural Research of the F.A.O. European Commission on Agriculture.

The Secretary of the Council, at the invitation of the Canadian Government, visited research laboratories and experimental farms in Canada in order to advise on the future organisation of the Canadian agricultural research services.

BUILDINGS AND PROPERTY

Major schemes completed during the year included the provision of special purpose glasshouses for the Physiology, Insecticide, Chemistry and Mycology departments at the Glasshouse Crops Research Institute. Various minor projects (including a new canteen building specially designed to cater for staff working in the isolation areas) were carried out to complete the large development programme at the Foot-and-Mouth Disease Research Institute, Pirbright. Extensions to the experimental dairy at the National Institute for Research in Dairying were also completed.

The major works in progress at the end of the year 1957-58 were:—

Animal Breeding Research Organisation: laboratory for climatological studies, mainly in sheep.

Glasshouse Crops Research Institute: mushroom research buildings.

Hannah Dairy Research Institute: extended laboratory and animal accommodation for the Nutritional Physiology department.

Houghton Poultry Research Station: new laboratory wing and adaptation of main building for administration.

Animal Diseases Research Association: animal accommodation.

National Vegetable Research Station: permanent laboratory block.

National Institute for Research in Dairying: new laboratories for the Bacteriology and Chemistry departments.

Plant Breeding Institute: special purpose glasshouses for plant pathological investigations and research on potatoes and brassicae.

Poultry Research Centre, Edinburgh: establishment of a sub-station for large-scale investigation of problems affecting the performance of poultry stocks.

Rothamsted Experimental Station: special-purpose glasshouses for the Insecticides and Entomology departments.

Rowett Research Institute: animal accommodation for the Physiology department.

Virus Research Unit, Cambridge: additional laboratory block.

The Council gave their support to a proposal for extensive new laboratory accommodation at the Macaulay Institute for Soil Research, Aberdeen, and also approved in principle the undermentioned major schemes:—

Field Station, Compton: additional laboratory accommodation.

Glasshouse Crops Research Institute: administration block.

Houghton Poultry Research Station: unit for research on leucosis.

Long Ashton Research Station: new laboratories, canteen and common-room block.

National Institute of Agricultural Engineering: new laboratory.

As a consequence of the transfer to the Council of responsibility for providing Government grants for the State-aided Institutes in England and Wales, the Ministry of Agriculture, Fisheries and Food conveyed to the Council the ownership of the freehold of certain properties occupied by the Foot-and-Mouth Disease Research Institute, Pirbright; The Glasshouse Crops Research Institute, Littlehampton; the Grassland Research Institute, Hurley; the National Institute of Agricultural Engineering (Wrest Park Lodge); the National Vegetable Research Station, Wellesbourne; and the Plant Breeding Institute, Cambridge. These properties amount in all to some sixteen hundred acres.

LAND AGENCY SERVICE

Reference was made in last year's Annual Report to the institution by the Council of a Land Agency Service provided by a private firm, Messrs. W. H. Cooke and Arkwright. The successful operation of this Service during the first year satisfied the Council that its continuance for a further three years was fully justified.

AGRICULTURAL RESEARCH FUND

The greater part of the Council's expenditure is met from the Agricultural Research Fund which is financed by a Parliamentary grant-in-aid. In the financial year ended 31st March, 1958, gross current expenditure was £3,606,419; capital expenditure on buildings and special apparatus amounted to £523,798.

A grant-in-aid of £3,862,000 was voted by Parliament, the whole of which was drawn. The grant-in-aid was augmented by receipts totalling £234,418 derived from sales of livestock, produce, etc., at research institutes and units, from rents and hostel charges, and from the sale of publications and reports, as well as by contributions totalling £37,525 from Government Departments and other sources. These contributions included £13,072 from the Hops Marketing Board and the Institute of Brewing towards the cost of research on hops at Wye College; £10,000 from the Animal Health Trust towards the maintenance of the Houghton Poultry Research Station; £6,523 from the Colonial Office towards the cost of the Council's Unit of Experimental Agronomy; £5,917 from the Colonial Office towards the cost of work on tropical soils and for research on insecticides at Rothamsted Experimental Station; and £2,013 from the Forestry Commission for research at Rothamsted on the nutrition of forest trees.

The allocation under main heads of the total expenditure from the Agricultural Research Fund was as follows:—

	£	Percentage of total
Administration	121,557	2·9
Research institutes and units of the Council:		
Current expenditure	1,008,020	24·4
Capital expenditure	103,447	2·5
Special research grants... ..	158,317	3·8
Studentships, training awards and fellowships (including travelling fellowships for visits overseas)	41,266	1·0
Grants to independent research institutes (England and Wales):		
For current expenditure	2,277,259	55·2
For capital expenditure	420,351	10·2
	£4,130,217	100·0

GRANTS MADE FROM THE VOTE OF THE DEPARTMENT OF AGRICULTURE FOR SCOTLAND

Grants to the independent agricultural research institutes in Scotland are made from the Vote of the Department of Agriculture for Scotland, on the advice of the Council. For the financial year which ended on 31st March, 1958, the total of such grants was £703,060 for current expenditure and £64,041 for capital expenditure.

BENEFACTIONS

By the terms of its Charter, the Council is empowered to accept and administer private funds or properties which may be given or bequeathed to it in trust, either for the general purpose of its work or for special objects within its field.

(a) *The Underwood Fund*

This fund has continued to be used by the Council to provide Fellowships for distinguished overseas scientists who wish to visit this country and who are likely, directly or indirectly, to assist the Council's work. The Council is willing to consider applications for Fellowships by, or on behalf of such scientists, at any time of the year.

Two awards were made in 1957–58. The first enabled Dr. C. P. McMeekan, Director of the Ruakura Animal Research Station, Department of Agriculture, New Zealand, to spend three months visiting research centres in this country.

The second was a grant of £500 towards the expenses of Professor F. W. Lorenz, of the Department of Poultry Husbandry, University of California, who spent a period in this country.

During the financial year 1957-58 the income of the Fund was £3,072; payments out of the Fund were £1,910. The balance on current account at 31st March, 1958, was £3,051.

(b) The Wain Trust Fund

By the generous benefaction of Professor R. L. Wain an income from the patents on his discoveries in the field of selective herbicides has been made available to the Council and has been used to establish the Wain Trust Fund. The objects of the fund are to facilitate the interchange of scientists between universities in the United Kingdom and overseas; to provide equipment in universities in the United Kingdom for agricultural research; and to further other schemes of benefit to agricultural research for which the ordinary funds of the Council are not available.

FINANCIAL ASSISTANCE FROM OUTSIDE BODIES

The Council gratefully acknowledge the assistance received during the year from the following bodies:—

(1) W. K. Kellogg Foundation

The Foundation has again provided four fellowships to enable research workers in this country to visit the United States and has again made available £1,000 in dollars for the purchase of scientific equipment.

(2) Hatley Foundation

From the monies placed at the disposal of the Council by the Foundation to enable agricultural research workers to visit North America, two grants amounting to \$2,700 were made.

(3) Rockefeller Foundation

The Foundation made grants of \$9,500 to the Macaulay Institute for Soil Research for the development of spectrochemical methods of analysis and \$10,000 to the National Institute for Research in Dairying as a contribution towards the purchase of special scientific equipment.

The Council also wish to express their thanks to the trustees of the Rockefeller Foundation, Lalor Foundation, Nuffield Foundation and the Wellcome Trust for the awards of travelling fellowships made during the year to members of the staff of the research institutes.

The gift by Messrs. Fisons to the Council's Unit of Experimental Agronomy, Oxford, of a logarithmic sprayer, is also gratefully acknowledged.

NORTHUMBERLAND

Chairman of the Agricultural Research Council

W. K. SLATER

Secretary of the Council

Cunard Building,
15, Regent Street,
London, S.W.1.

20th January, 1959.

SOME ASPECTS OF AGRICULTURAL RESEARCH

Mention was made in the Council's report for 1956-57 of the intention in future years to present, in a form suitable for general reading, a series of articles, each of which would cover a selected topic within the sphere of agricultural research. In pursuance of this policy the following articles have been prepared.

POULTRY RESEARCH IN GREAT BRITAIN

Probably no other branch of agriculture has expanded at the same speed or to the same extent as the poultry industry. Before the first world war it was little more than a backyard hobby, but by 1938 it was the third most important branch of agriculture, with an annual output worth some £30 million. During the second world war the industry was reduced by rationing to almost half its pre-war level. Since 1945, however, the expansion has been even more spectacular than that which occurred between the wars and it is now the second most important of the agricultural commodities, with an output in the year 1957-58 worth £204 million.

The poultry industry has felt the impact of intensive management to a greater extent than any other branch of the industry dealing with livestock. Today between 50 and 70 per cent of birds kept for commercial egg production are intensively housed, whilst in the table poultry industry the figure must be nearly 100 per cent. Even in the breeding of poultry intensive methods are fast gaining favour; chick production is now a very highly organised business and walk-in incubators of very large capacity have been developed for it.

This trend has been accompanied by a marked increase in the size of the flock. In seven years the number of specialist units has trebled and the average number of birds on each unit has doubled. The broiler industry, virtually non-existent in 1950, has now reached an output of over 50 million birds a year and may well reach 100 million by 1960, if this rate of expansion is maintained. The expansion of the turkey industry has also been extremely rapid and the present population of nearly 3 million birds is practically double what it was three years ago.

Prior to the outbreak of the second world war there was little organised poultry research in Great Britain although at a number of University Departments, Veterinary and Agricultural Colleges and at the National Institute of Poultry Husbandry there were a few workers who either regularly or occasionally gave some attention to the subject; but nearly all had other duties, such as teaching, advisory work or diagnosis. Today there are two institutes wholly concerned with poultry research, the Poultry Research Centre, Edinburgh, and the Houghton Poultry Research Station, the former wholly financed by the Agricultural Research Council and the latter partly so, having been established by the Animal Health Trust. The facilities at both these institutes are still being expanded. Poultry problems are also being studied at a large number of colleges and university departments throughout the country. The Veterinary Laboratories of the Ministry of Agriculture, Fisheries and Food at Weybridge and at Lasswade have done much valuable work on avian disease and the Ministry's Experimental Husbandry Farms undertake poultry investigations mainly in connection with housing problems. Valuable contributions have come from the Ministry of Agriculture in Northern Ireland, and from the Department of Scientific and Industrial Research at their Low Temperature Research Station in Cambridge.

The growing volume of poultry research, not only here but throughout the world, is reflected in the fact that between 1950 and 1957 approximately 600 papers dealing with poultry investigations have been published in Great Britain alone. It is clearly impossible to present a complete review of the development of research during this period and only a general outline of the more important work going on at present will be given. Even so there is much excellent work in progress to which it has been impossible to refer.

It is essential, in considering the nature and adequacy of present research on poultry, to appreciate the problems confronting a rapidly expanding industry which result from increasing unit size and density and the use of artificial methods of husbandry. The control of disease is a most obvious problem; even as long ago as 1938 the loss to the poultry industry from disease was estimated at £4 million annually; by 1954 this estimate had risen to not less than £10 million. The cost of food is a major item in keeping birds and more needs to be known about the feeding of intensively kept birds, the nutritional requirements of laying stock for efficient and profitable egg production, and the nutritional requirements of table poultry both for economical food conversion and the development of good carcase quality. The most suitable environmental conditions for all stages of the bird's life must be defined and methods elaborated for achieving and maintaining these conditions. Genetical problems arising out of practices such as hybridisation and strain crossing, which are already being employed commercially, are also of great importance.

GENETICS

So far most genetical work has been concerned with egg production.

The operation of the Poultry Progeny Testing Scheme, enabling breeders to assess the efficiency of their own methods of selection, will almost certainly result in a demand for advice on means of improving these methods. Research based on recent theoretical work on quantitative genetics is, therefore, being directed to the improvement of breeding systems, and the special problems of the small breeder are being borne in mind. More information is also needed on the extent to which the relative merit of different strains depends on the type of management under which they are kept.

Inbred lines of Brown Leghorns and some of the crosses between them are being kept at the Poultry Research Centre in a variety of environments, including unheated floor pens, battery cages and a constant environment chamber, so that the interaction between genotype and environment can be explored, especially in regard to production traits, mainly egg production and hatchability. This work will also throw some light on the nature of hybrid vigour and on problems associated with the production of commercial hybrids. Earlier work on this closed flock of Brown Leghorns has already provided data on characters such as quality and hatchability of eggs, growth rate, time of maturity, egg production, food conversion efficiency and early mortality for each line and had exposed quantitative differences between them. Crosses are now being made between selected lines which show differences in particular characters. So far as obtaining high egg production by hybridisation is concerned, it has shown that some of the initial vigour of the original cross may be retained by repeated back-crossing.

A scheme of family selection, based on a simplified version of the Lerner system, is being studied at Wye College in order to find a method of testing which can be confidently recommended to the industry, together with an indication of the cost of the improvement. At the same time information will be gained on the effects both of breeding under intensive conditions, and of selection for high egg production on other characteristics such as body weight and conformation. A similar study is being made at the National Institute of Poultry Husbandry where the long-term effects of a prescribed system of selection and mating within

the practical and financial compass of the small breeder is being explored. The Institute is using eight lines of White Leghorn and eight of Buff Rocks which have been maintained for some time as closed lines, and the suitability of their foundation stock for the production of in-cross and in-crossbred hybrids is being examined. Heaviest weighting has been given in their programmes to those qualities, namely viability and the yield of eggs in the first 500 days, which have the greatest influence on the profitability of egg production.

Similar studies are also being carried out at the East of Scotland College of Agriculture and at the Agricultural Research Institute of Northern Ireland, situated at Hillsborough. At the former an attempt is being made to improve a closed flock of White Leghorns by family selection and progeny testing and to compare the results of pure breeding and strain crossing. At the latter institute the heritabilities and genetic correlations of resistance to disease, egg production traits and growth rates are being measured in a White Wyandotte flock.

Too little attention has so far been given to the breeding of table poultry in spite of the fact that the important qualities have high heritabilities and progress should be rapid. The National Institute of Poultry Husbandry is concerned with the long-term effect of applying a specific system of family selection to stock intended for meat production and with the value of such selected stock for the further production of hybrid stock. Five closed lines of Light Sussex have been established and the main objective is to produce rapidly growing, hardy birds of good conformation, with white plumage and skin, with both sexes marketable as broilers at 12 weeks of age at the latest. In selecting the breeding stock, heaviest weighting is given to those characteristics influencing the profitability of table poultry, namely, rapidity of growth to marketing weight, low mortality and good egg yield of the parent stock.

In the breeding of turkeys one of the principal problems is how to combine the rapid growth, efficient food conversion and the good fleshing qualities associated with the broad-breasted birds, with satisfactory fecundity, for fertility within the breed tends to be low. Some strains, notably Beltsville White, have satisfactory fecundity, but they are characterised by a low mature body weight and an inefficient feed conversion ratio. The successful development of artificial insemination, at present somewhat limited by a lack of fundamental knowledge of semen dilution and storage, might lead to a solution of the fertility problems associated with the broad-breasted breed, but the ideal to be aimed at is the development by breeding of a strain combining a high fecundity with rapid growth and good food conversion.

The Department of Animal Genetics at Edinburgh University is interested in the fecundity of broad-breasted birds and is attempting to produce a true-breeding strain of turkey characterised by first class body formation and high fertility. Cross breeding seems to enhance fertility and the Department's approach to the problem is, therefore, first to produce a cross-bred family of good fecundity and then to mate this to males of a strain carrying excellent meat quality.

Breeding of turkeys is also going on at other centres which keep them for other purposes. A selection programme on family lines is in progress at the Sprowston Turkey Centre the aim of which is to maintain a uniform though improving flock suitable for use in feeding and other trials. A small flock of broad-breasted Bronze turkeys is maintained at Houghton for the production of poults for disease investigations and the breeding programme for these birds is again aimed at improving the flock. Hens are selected for medium size, good conformation, high egg yield and low incidence of broodiness. They are mated to stags of good conformation, which have reached sexual maturity early and have given reasonable semen yields throughout a season and have good dam

records. This programme has produced in the third generation an increase in body weights in both sexes, and an increase in keel length resulting in a better balanced bird.

ARTIFICIAL INSEMINATION

The usefulness and consequent rapid growth of the practice of artificial insemination in cattle has stimulated investigations into the practical application of A.I. in birds. Techniques and equipment for the collection and insemination of semen have been developed at Houghton over a period of years. The results obtained by their use have been given some publicity and in consequence artificial insemination of turkeys is now fairly common, but there is still much to be done. Investigations have been carried out on the effect on fertility of diluting and storing fowl and turkey semen, and an attempt has been made to determine the fertilizing capacity of males by the examination of their semen, using various laboratory techniques. The physiology of reproduction in both males and females is being studied at the Poultry Research Centre. Attempts are being made there to improve diluents for avian semen by studying the chemical composition of seminal plasma, and the chemical changes which occur in spermatozoa and plasma. A related problem also being investigated is whether seasonal fluctuations in fecundity are accompanied by changes in semen quality. On the female side, the secretions of the oviduct, particularly of those regions where spermatozoa are stored, and where fertilization occurs, are being investigated.

DISEASE

The greater the density of population the more artificial the conditions, and the longer the animals are kept in one place the more likely is disease to arise and the more disastrous can the consequences be. The methods of managing poultry which from other points of view are most economical tend unfortunately to be just those that favour epidemics; and the combating of disease is a major preoccupation of the industry. At present fowl paralysis and leucosis dominate the disease picture but respiratory diseases are very troublesome and can spread very quickly. Salmonella infections and coccidiosis also remain major problems.

It has been estimated that approximately one-third of the mortality in poultry is due to fowl paralysis and the complex of diseases collectively called leucosis, and that these conditions alone cause an annual economic loss of at least £4 million. There can be no doubt that the most serious weakness of poultry research lies in this field. In view of the widespread occurrence of fowl paralysis and leucosis in this country, the first requirement of an expanded programme of research is a supply, for experimental purposes, of stock which is free of the disease yet susceptible to it; and a unit for producing such stock is being planned. The establishment at Houghton of an experimental unit which will be devoted solely to the study of fowl paralysis and leucosis is also under consideration.

It was mentioned that leucosis is a complex of diseases, and information on types of leucosis in poultry generally and in selected stocks is being recorded at Lasswade. In connection with this an investigation has been made in collaboration with the Veterinary School, Edinburgh, into the effect of environment on the incidence of fowl paralysis in different strains of birds. Preliminary work is in progress on the possibility of isolating the causal agent or agents of lymphoid leucosis at the Veterinary School, Bristol, by the use of tissue culture technique, and by transmission and transplantation of material from field cases. The possibility of applying paper electrophoresis to the diagnosis of avian leucosis is being explored at Houghton where abnormalities of the serum-protein and amino-acid patterns are being studied in the plasma of chickens in which liver damage has been caused by transplantation of lymphoid tumours.

Many different substances have been developed for use in the struggle against human cancer and it would seem only logical to see what effect the more promising of these have on the development of tumours in the bird. Several compounds of this nature have in fact been tried. Unfortunately, although in some instances these compounds restricted growth of the transplantable tumours, they were highly toxic.

A number of interesting observations on leucosis have been made at the Poultry Research Centre. It has been shown, for example, that certain types of tumours developing in the reproductive organs can be detected in their early stages by means of a liver clearance test. It has also been shown that when certain types of viruses which produce fowl tumours are injected into chicks, new types of cancer may appear and the properties of these virus-induced cancers are being studied both chemically and with the electron microscope. The possibility that nucleic acid may be a carcinogenic factor in such tumours is being investigated. Another approach to this problem may be provided by the fact that symptoms indistinguishable from those seen in fowl paralysis are produced when birds are injected with brain tissue taken from normal fowls.

Respiratory diseases are probably the second most important group of poultry diseases and their incidence is increasing with the present rapid development of intensive poultry keeping. This group of diseases includes infectious bronchitis, infectious laryngotracheitis, chronic respiratory disease (and infectious sinusitis in turkeys) Newcastle disease (fowl pest), fowl pox and fowl coryza (*Haemophilus gallinarum* infection). A number of centres are working on these diseases at present but still more research is urgently required on their control in view of the rapidity with which they may spread.

The aetiology of certain respiratory diseases in poultry, particularly infectious laryngotracheitis and infectious bronchitis, is being studied at the Veterinary School, Liverpool, and progress has been made in developing techniques for their diagnosis and differentiation. A watch has been kept on a number of farms in Lancashire, Cheshire and Shropshire in order that a detailed study could be made of outbreaks of infectious laryngotracheitis.

It is well known that pleuro-pneumonia-like organisms (p.p.l.o.) are associated with chronic respiratory diseases in poultry, and with infectious sinusitis in turkeys, though the exact significance of these organisms in the cause of these conditions is not yet clear. This problem has attracted the interest of the workers at the Veterinary School at Cambridge. These organisms can be found not only in chickens affected with chronic respiratory diseases but also in chickens suffering from other respiratory diseases and even in normal fowls. Pleuro-pneumonia-like organisms, however, differ in their pathogenicity, and in other characteristics, and the work at this School tends to show that the diagnosis of chronic respiratory disease should depend on the identification of the specific pathogenic p.p.l.o.'s rather than on the isolation of p.p.l.o.'s in general as at present. It has been shown that some outbreaks of chronic respiratory disease are due to secondary complications following one of the virus infections, i.e. infectious bronchitis, infectious laryngotracheitis and Newcastle disease.

A necessary part of the work at Cambridge has been the devising of techniques for growing various avian viruses in tissue cultures. This aspect of the work may have an importance of its own for it may lead to the development of vaccines based on cultures of mammalian tissues. If these could be developed their use would avoid the risk of transmitting egg-borne agents, which is present when eggs have been used for the preparation of the vaccines.

Experimental work continues at Weybridge on the production of vaccines suitable for use against Newcastle disease. Preliminary trials are being carried out with a vaccine in which the virus has been inactivated by β -propiolactone;

fowls inoculated with this vaccine have successfully withstood challenge with virulent Newcastle disease.

The genus *Salmonella* consists predominantly of bacteria that inhabit the alimentary canal of animals and man. They may be catholic in their choice of host and may be carried for long periods in resistant or recovered hosts without symptoms. They are important causes of food poisoning in man and they are organisms which need to be considered in relation to hygienic management and marketing practices. The group also contains the organisms *Salmonella pullorum*, responsible for pullorum disease, and *Salmonella gallinarum*, responsible for fowl typhoid. It has been shown at Houghton that furazolidone is an effective drug for the treatment of diseases caused by this group of organisms, and that it can be used as an adjunct to the blood test in the control of chronic carriers of *pullorum* disease. Investigators at Weybridge have shown that a form of arthritis in broiler chicks is caused by a variant strain of *S. pullorum*. The disease is apparently egg-transmitted, and the "carrier" parents may fail to react to the routine blood test. The results of an extensive survey, however, do not suggest that the incidence of this variant is such as to interfere seriously with routine blood testing for *S. pullorum* infection.

The incidence of fowl typhoid has increased very considerably during the last few years and it can now be regarded as a major cause of mortality in certain areas. Work at Houghton indicated that furazolidone is an effective drug for the treatment of this disease. Subsequently two live vaccines have been elaborated there. The mortality in a group of birds vaccinated with one of these (9R) and subsequently challenged with fowl typhoid was only 6.5 per cent compared with 70 per cent in non-vaccinated birds similarly challenged; and in the majority of cases vaccinated birds did not react to the routine blood test. The vaccine has now been made available to the poultry industry for use where appropriate. The embryonic and chick mortality, commonly termed "yolk sac infection" or mushy chick disease, which results from infection of the yolk, is being investigated at Houghton and it has been shown that a number of bacteria frequently present in the alimentary tract and on the skin of the hen can infect the yolk and kill the embryo. Two outbreaks have been investigated in which a staphylococcus of human origin has been incriminated. An extension of this work, in which hens were kept under various types of management, using deep litter, wire floor pens, battery cages and strawyards, indicates that the bacterial flora of the shell is influenced by the type of management of the breeding flock. Hay, straw, stale faeces and deep litter all contained considerable numbers of bacteria able to penetrate the shell and utilise the nutrient matter of the yolk. Contamination with these organisms may lead to a decrease in the storage life of eggs intended for consumption and a decrease in the hatchability of eggs used for chick production. These results indicate the advisability of using material with a relatively low content of bacteria, such as sawdust or wood shavings, for nest box linings, and of renewing it frequently, and they point to the necessity for the immediate removal of faecal matter from nest boxes and the regular and frequent collection of eggs.

An epidemiological study is being made at Lasswade of the transmission of *S. typhimurium* via the egg. At the Laboratory and at Houghton extensive work which has been of considerable benefit to the industry has been carried out on the disinfection of incubators and hatchery premises with formaldehyde and furfuraldehyde and by the use of aerosols composed of ethylene glycol and chlorinated phenols and formalin.

Work at Houghton has also shown that shell-borne infections can be controlled by the dipping of hatching eggs in certain germicidal solutions.

An extensive study has been carried out for some years both at Weybridge and Houghton on the chemotherapy of avian coccidiosis and the efficiency of

sulphonamides, nitrofurazone and nicarbazin in preventing and controlling the caecal type of the disease has been established. There is little doubt that this work has largely revolutionised chick rearing and the production of broilers would well nigh be impossible in the absence of such coccidiostats. It is sometimes found that one drug will enhance the activity of another and it has been shown that the activity of certain sulphonamides can be increased approximately ten times by using them in conjunction with anti-malarial and certain other drugs. The practical application of this technique has yet to be established, however, as one of the synergistic drugs has unfortunately proved to be toxic to chickens.

A detailed study is now being made of the infections produced by pure cultures of the various organisms which give rise to intestinal coccidiosis. It has been shown that drugs widely used in the control of caecal coccidiosis are not necessarily as effective in controlling the intestinal forms of coccidiosis. Tests of six such drugs suggest that, in order to obtain the most effective results in the treatment of the intestinal forms of the disease, the particular species of coccidia concerned in any outbreak should be identified. Sulphaquinoxaline has been shown to be the most effective drug for the treatment of the common form of coccidiosis in turkeys.

The incidence of epidemic tremors (avian encephalomyelitis) has increased during the past two years and the condition is now a serious cause of chick mortality. Investigations at Weybridge indicate that the disease cannot be transmitted by direct contact between chicks and it would appear to be egg-transmitted although the exact method of spread is obscure. So far no method has been elaborated for the detection of carrier adults.

Diseases of the kidney are of considerable economic importance, and research continues at Weybridge on the pathology and treatment of Pullet Disease. At the Poultry Research Centre a study is being made of the histology of spontaneous diseases of the kidneys and at least two conditions can now be differentiated. Further work is being carried out on the nature and cause of avian kidney disease and attempts are being made to reproduce kidney disease experimentally by the injection of foreign proteins, by the implantation of oestrogens, and as a sequel to stress and chronic liver damage. The tetracyclines have been shown to be of some value in the treatment of certain field outbreaks of pullet disease.

The haemorrhagic syndrome and roundheart disease are also being investigated, but the aetiology of both conditions is still obscure.

During the last year or so the occurrence of virus hepatitis amongst ducks on numerous farms in the Norfolk area has been confirmed. A detailed study has been made of this disease at Weybridge and it has been shown that a strain of the virus responsible for it can be used to immunise breeding stock. The immunised breeding stock confer upon their progeny a passive immunity, and ducklings hatched from eggs laid nine days after vaccination of the breeding stock were found to be resistant to the disease. Another successful method of vaccination which has recently been evolved is the stabbing of the web of the foot with a needle dipped in an attenuated strain of the virus. The vaccinated ducklings become resistant to the disease within 36 hours.

At Houghton and Weybridge work is continuing on the use of various drugs for the prevention and treatment of blackhead in turkeys. A study is being made of the methods of transmission of this disease and the role in this of the caecal worm of the fowl. A search is being made for a practical disinfectant against the eggs of the caecal worm. Of the drugs studied, the efficiency of acinitrazole and, to a lesser extent, of furazolidone, has been clearly demonstrated. The latter drug has also been shown to be effective for the treatment of hexamitiasis.

NUTRITION

Great advances have been made in the whole field of nutrition and it is probable that within this field progress has been most rapid in respect of poultry. In spite of this, problems still arise with regard to the feeding of poultry of different ages and types under conditions of intensive husbandry. Feeding costs remain the highest single item in the production of both eggs and table poultry and the major emphasis of future research must be on improving the food conversion ratio and lowering the cost of the ration, whilst at the same time achieving early maturity in table poultry and high hatchability in eggs from breeding stock. The particular aspects receiving most attention at present are energy and protein requirements.

Studies of the efficiency of food utilisation for egg production using high and low energy diets have shown that, although birds on a low energy diet eat more total food, the intake of digestible food, the egg production and the cost per year are the same on both diets. The low energy diet (mainly oats and wheat offal), by comparison with the high energy diet, saved in a year nearly two tons of fishmeal and over one ton of other protein concentrate per 1,000 birds. The cost per bird, however, was the same for both diets as the birds on the low energy diet ate more food.

The fibre content of layers' diets containing low fibre cereals was reduced to the lowest amount possible in an experiment at Hillsborough that lasted for two years. It was found that some 50 per cent more food was required to produce one dozen eggs on low energy diets as compared with high energy diets. Evidence of a decrease in egg production with high energy levels is being assessed. These experiments are being extended to include the addition of fat to the high energy diet.

An experiment on the efficiency of a diet of whole grain supplemented with a high protein pellet has been completed and showed that a concentrated pellet containing 50 per cent fishmeal, when fed as a supplement to a diet of whole grain at a level of 10 per cent, can support satisfactory egg production in semi-intensive conditions.

The effect of varying energy and protein levels in the diet of broilers has also been studied at Reading University, where it has been shown that added fat has no growth-promoting property beyond that to be expected from its energy content. With narrow calorie/protein ratios depressed growth and high mortality have been demonstrated. Further work is being carried out to determine whether the range of calorie/protein ratios which supports optimum growth and food conversion varies with the energy level of the diet.

At the Rowett Institute more accurate methods of assessing the nutritive value of foodstuffs have been designed and are being used to devise more economical rations. Protein concentrates have been found to be variable in the quality of their protein, much of this variability arising from damage during processing. A collaborative trial with other laboratories is in progress to see whether there is a sufficiently good correlation between biological and laboratory tests for protein value to enable the more rapid laboratory tests to replace the biological test for most purposes.

Work at Reading University has shown that when best white fishmeal has been used as the sole protein supplement of a breeder's diet a depression occurs in the hatchability of fertile eggs. These results have been confirmed in collaborative work at Houghton. The depression does not seem to be caused by a simple vitamin deficiency. Work is proceeding in order to assess the level at which fishmeal may safely be fed and to determine what proteins may be used as substitutes for fishmeal to maintain high production while avoiding a depression in hatchability.

An experiment comparing high quality mash with cereals and skim milk has been completed at Hillsborough. The results show that a milk and cereal diet, even when supplemented with methionine, choline and extra fat, is incapable of producing rates of growth comparable with those that can be obtained with a high quality dry mash. An examination has also been made at the Rowett Institute of the relationship between growth and amino-acid composition of protein concentrates. As a part of this work the effect on growth of supplementing cereal protein in the diet of chicks with amino-acids alone or in combination is being investigated, as well as the effect on egg production of the relative proportions of amino-acids in the protein supplement of the ration for birds kept intensively.

Three Experimental Husbandry Farms of the Ministry of Agriculture, Fisheries and Food are studying the rearing of young laying stock from the age of eight weeks on oats and good pasture, rather than on a standard growers' meal ration. At one centre where the work has been in progress for some years results favour the chicks reared on whole oats.

Experiments are in progress at Sprowston to determine whether feeding a high energy ration to turkeys from 2-24 weeks of age enables the required degree of finish to be obtained at an earlier age than is possible with a normal finishing ration and to find whether the addition of fat to a high energy ration gives any advantage in growth or finish.

The influence of nutrition on certain bacterial and protozoan infections (fowl typhoid and blackhead) is being investigated at Houghton. Earlier work had indicated that the incidence of fowl typhoid was lower in birds fed a ration of ground wheat than in birds fed more complex rations containing high levels of fishmeal. Similarly, by feeding only grain, or by adding 20 per cent of oat fibre to a normal growers' ration, mortality due to blackhead in chicks could be reduced by nearly one-third of that occurring when normal growers' rations are fed. The feeding of high levels of all the vitamins that are needed had no effect on the mortality rate or survival time of chickens artificially infected with fowl typhoid. The next step is to uncover, if possible, the mechanism responsible for the differential resistance to these diseases and the work is being continued with this in mind.

As the use of antibiotics often features in management practice it may be convenient at this point to recount very briefly the sort of work that is in progress on this subject. The National Institute for Research in Dairying is particularly interested in the mode of action of antibiotics especially in their effects on the gut, and in pursuit of this a study of the bacteriological flora of normal and antibiotic-fed chicks is being made. It has been noted that the feeding of penicillin for several generations has no cumulative effect. The performance of hens given this antibiotic may be slightly but not significantly improved; their mortality, however, is lowered and the production and hatchability of their eggs and the growth of their progeny is better.

The effects of antibiotics on the growth of chickens fed high quality diets are being studied at Hillsborough, and the strength of shells of eggs laid by hens on diets containing different levels of calcium and antibiotics is being measured.

The effect of certain antibiotics—and also of radiation—on the storage life of chilled eviscerated poultry is being examined at the Low Temperature Research Station. An assessment is being made of the influence of antibiotics on the number of bacteria present and on the development of the peculiar odour which indicates lack of freshness. The results do not show that any advantage is to be gained by antibiotic treatment under existing methods of processing in this country. The use of antibiotic supplements in the food prior to slaughter

appears to nullify the preservative effect of antibiotics used after slaughter and to lead to the development of antibiotic-resistant strains of certain streptococci.

There have been numerous reports in the medical and veterinary literature of the emergence of bacteria resistant to antibiotics. It has been shown both at Houghton and the Low Temperature Research Station that chicks fed on tetracyclines at low levels (25 p.p.m.) continuously, or at high levels (400 p.p.m.) intermittently, very soon excrete both coliform bacteria and streptococci resistant to the antibiotic used. This work is now being extended to investigate the behaviour of *Salmonella* organisms and there is already an indication of an increase in the antibiotic resistance of *Salmonellae* excreted by chicks fed antibiotic.

This latter work is in its early stages but it raises a question of great importance, namely, whether the use of antibiotics as a method of extending the shelf life of poultry is accompanied by a hazard to the public health. The work at the Low Temperature Research Station already mentioned has shown that dipping in tetracycline failed to extend the storage life of eviscerated poultry carcasses in the absence of refrigeration. The type of spoilage bacteria which so characteristically alter the product in a manner recognisable as dangerous were absent and had been replaced by an extensive growth of yeasts and moulds resistant to the tetracycline used. Like these yeasts and moulds *Salmonellae* can be resistant to antibiotics and these organisms, too, could flourish during the storage of an antibiotic dipped carcass, yet because of the absence of normal spoilage bacteria the carcass would give no indication by flavour or smell that it was dangerous.

It has also been shown at Houghton that bacteriostatic concentrations of tetracycline are present in the serum of chickens within a few hours of their being placed on a ration containing a high level of antibiotics. This work suggests that the feeding of large amounts of tetracyclines for a short time should be more effective for the control of disease than continuous medication on lower levels.

HOUSING AND MANAGEMENT

The optimal conditions under which different classes of poultry should be kept are very imperfectly understood and the lack of such information makes it impossible to design with confidence ideal accommodation of any type. The lack of knowledge is most apparent, and also of the greatest urgency, in the case of broilers.

Information is needed principally on the effects of light, temperature, relative humidity, air changes and carbon dioxide concentration on all classes of stock and basically there are two different ways of obtaining the information. The first, which is being followed at the Poultry Research Centre and Houghton, is to make a detailed study of the behaviour of birds kept under carefully controlled laboratory conditions.

The component in the environment which is most easily controlled is light and as light has a very real influence on the laying bird its effect has already been extensively studied. Nevertheless there is still much to learn and some new lines are being pursued at Reading University. It has been shown, for example, that winter egg production can be increased by the use of 10 flashes of light of 20 seconds duration at 15 minute intervals; a response can be obtained equivalent to that produced by a conventional 14 hour day.

It has also been shown that the onset of sexual maturity of the fowl is affected by the rate at which the length of the day is changing throughout the growing life of the bird. The average length of the day seems to be unimportant, but increasing the length of the day advances maturity and decreasing the length of the day delays it. A further experiment in progress is, therefore, an attempt

to delay sexual maturity in December-hatched pullets with a view to increasing the size of the eggs they will lay. So far it has been found that when pullets were given artificial light so that day-length decreased uniformly from 24 hours at day-old to the natural light level at the time they were transferred to their laying quarters, the onset of laying was delayed by three weeks and an improvement in early egg size obtained.

A study of the effect of environment, including light, on the domestic fowl has been going on for some years at the Poultry Research Centre, particularly in relation to the seasonal variations in egg yield and the diurnal rhythm of body temperature. Carefully controlled environmental conditions have also been used in a study of the effects of climate on other factors of economic interest such as growth, reproduction and viability. Attempts are being made at Houghton to obtain basic information on the rate of production of water, ammonia, hydrogen, methane and carbon dioxide by chicks and to measure their respiration and heat production. For this purpose a constant-temperature calorimeter has been designed and erected. The environmental temperatures needed to obtain optimal growth throughout the life of broilers and the ventilation rates required by them are also being studied.

The alternative way of approaching this problem is to measure the conditions that prevail in a variety of existing houses and to correlate these with the productivity of the birds in the different houses. This approach also provides information on the environmental conditions to be expected in houses constructed and managed in different ways.

A survey of this type is being conducted from the Royal Veterinary College, London, with the object of studying the influence of the type of housing on broiler productivity. Temperature, humidity, condition of the litter and productivity are being recorded in some thirty different houses, and estimates of carbon dioxide, ammonia concentration and heat production in them are being made. Investigations include comparisons of the efficiency of different types of brooder and an evaluation of the relative effectiveness of various building materials. It is hoped in this survey to study different types of housing in relation to their labour requirements and the management of litter, and to see if any correlation exists between litter conditions on the one hand and ventilation rates, heat insulation, mortality and subsequent grading of the birds reared on the other. The optimal house temperature during the post-breeding period, the ideal ventilation rate for broilers of different weights, and the maximum permissible air speed in broiler houses are also being studied.

A similar survey is in progress at the Veterinary School, Cambridge. The types of houses being studied are:—(1) naturally ventilated houses; (2) mechanically ventilated houses with windows; and (3) mechanically ventilated houses with controlled lighting. The results so far indicate that during the summer well-insulated houses and houses with thermostatically-controlled fan ventilation have many advantages over other types. The conditions that prevail in these houses compare favourably with those believed to be optimal for economic growth, and sudden fluctuations in temperature, humidity and air velocity are minimised. This survey aims at a tentative definition of standards for ventilation and temperature in broiler houses.

In view of the increasing extent to which poultry in general, and hatchery supply flocks in particular, are kept under intensive management, it is a matter of some urgency to determine the long-term effects of continuous breeding and rearing under intensive housing conditions. At the National Institute of Poultry Husbandry an investigation dealing with the problem has already been carried on for four years. A closed flock of Buff Rocks has been maintained under intensive conditions, generation by generation, from day-old until the end of

reproductive life. This flock is being compared with control flocks which have been reared either intensively or extensively and then housed semi-intensively during the laying period. An additional control flock has been housed in a laying battery. Although the results have not yet been examined in great detail, nothing has been found so far which would detract from the value of the intensive system of management. Egg production, body weight and rate of mortality, for example, are the same as they were in the original foundation stock. It would also appear that improved fertility may be expected under intensive breeding and this, together with the increased production obtained under intensive management, should lead to more efficient production of hatching eggs.

A somewhat similar experiment is in progress at the Gleadthorpe Experimental Husbandry Farm. A comparison is being made here of breeding stocks maintained in deep-litter houses and in colony houses; the progeny from these stocks are being reared under extensive and intensive conditions and then maintained intensively during the laying period.

By using a double shift system of housing, two laying flocks can be accommodated simultaneously in one unit without reduction in the floor space available to each bird. This ingenious idea has been tried at the National Institute of Poultry Husbandry. The results in the day shift were as satisfactory as those of a conventional single flock housed intensively, and there was no evidence that the performance was depressed by the inclusion of the extra night flock. Although the production from the night flock was lower, the capital invested in house and equipment yielded an increased return of over 50 per cent.

At the Great House Experimental Husbandry Farm an experiment has been in progress for three years to compare the efficiency of normal deep-litter housing, unheated houses and heated houses for the housing of laying stock. Birds for each house have been reared both outside and under controlled temperatures. Full records of various economic factors are being obtained and so far, although the birds reared outside and housed in insulated or heated houses have given slightly higher egg production, the additional eggs from the heated houses have not justified the extra cost of heating.

MARKETING

With the establishment of the Egg Marketing Board it became clear that more information is required about eggs, especially in relation to the quality of egg shell and contents, the invasion of eggs by bacteria and the transmission of disease by eggs, the effect on them of cleaning processes, and the best method of handling and storing them. A considerable amount of work is in progress on the quality of eggs, but it is related almost entirely to the problems of maintaining good quality in the egg after it has been laid; little is known about abnormalities in the quality of the egg when it is laid and it may be that a survey should be undertaken to ascertain the extent and nature of any such abnormalities. At the Low Temperature Research Station a study is being made of the structure of thick egg white and the factors responsible for its breakdown, particularly in relation to changes occurring with time.

The mechanism of penetration of bacteria into the egg and the multiplication of organisms responsible for rotting in eggs are being studied at the Low Temperature Research Station.

The effect of washing eggs with various detergent preparations is being explored in Northern Ireland. Washed and unwashed eggs were stored, some at room temperature for five weeks and some in cold store for six months. Results from the eggs stored in the cold are not yet available, but in the eggs kept at room temperature for five weeks there was less than 1 per cent of rotting in the unwashed, naturally clean eggs, 3 per cent in the dirty unwashed eggs and from 1.5 to 1.6 per cent of rotting in the dirty eggs washed in four different

compounds. The influence of nesting conditions and nesting materials on the rotting of eggs is being investigated; it has been found so far that between three and seven times as many eggs rotted from damp nests as from dry nests. Methods for the detection of cleaned eggs are being investigated at the Low Temperature Research Station.

An investigation of *Salmonella* organisms in liquid egg has shown that in order to ensure absence of these organisms it is necessary to heat-treat the product at 150° F. for 2½ minutes. The resultant liquid egg produced good foams and batters when tested by the British Baking Industries Laboratories. Work has also been carried out on the distribution of *Salmonellae* in liquid and frozen eggs which have been subjected to radiation.

The rapid expansion of the broiler industry has focussed attention on the need for more knowledge on the processing, storage, refrigeration and presentation for market of table poultry. Many problems in this field are being investigated at the Low Temperature Research Station. An investigation is being made there into the factors responsible for the greening of uneviscerated poultry carcasses and the production of hydrogen sulphide by organisms responsible for the spoilage of carcasses in poultry plants is being measured. The biochemical changes occurring in chicken muscle after death and the relationship of such changes to toughness are also being studied.

In an experiment at the National Institute of Poultry Husbandry, four methods of chilling of table poultry were compared, namely, cooling in air, immersion in water, cooling in water containing crushed ice, and the contact plate method; immersion in water containing crushed ice proved to be the most efficient.

Other work on the preservation of carcasses has been mentioned earlier, in discussing the work on antibiotics.

RESEARCH ON POTATOES

For many years potatoes were the most valuable crop grown in Great Britain. In the last five years their estimated gross annual value has fluctuated between £64 and £78 million. They are still the most valuable crop in most years, but in two of the last five years the value of the wheat crop has substantially exceeded that of the potato crop.

Experience in two world wars has emphasized both the importance of potatoes as a staple article of diet in the country and the importance of disease as a factor in their cultivation. At the end of the first world war there was an alarming spread of wart disease which could have become extremely serious had it not been for the finding of immune varieties. This, coupled with vigorous administrative action to prevent the growing of susceptible varieties on infested land, averted a critical situation. Since then all new varieties produced by plant breeders have been submitted to an immunity test and only immune varieties are now approved for registration and certification.

At the end of the second world war an almost equally serious situation was developing due to the spread of potato root eelworm. The trouble has been alleviated—though by no means overcome—partly by administrative action based on scientific research, and partly because a substantial fall in acreage has permitted rotations to be lengthened. Taken in conjunction with the well-known losses caused by blight and virus diseases, these examples emphasize the serious potential hazard of pests and diseases in potato growing.

Quite apart from the losses caused by disease, potatoes are an expensive crop to grow because of the high cost of seed, the amount of fertilizer needed and the number of cultivations that have to be given. Moreover, yields are

greatly affected by rainfall, manuring, sprouting of seed, spacing of seed, and other factors. It is, therefore, scarcely surprising that since the early 1920's a great deal of research and experimental work has been devoted to the crop. In the past ten years, for example, more than 200 papers have been published on one or other aspect of potato research. It will be possible to do no more here than review general trends in this research and indicate directions in which further research is now developing.

POTATO HUSBANDRY

No sharp dividing line can be drawn between research and field experimental work. The assessment of new varieties, the evaluation of fertilizers, studies on sprouting or "chitting", and many other lines of investigation may all involve both laboratory and field work. Most research stations have their own farms for field experiments, but in addition often seek the collaboration of such organizations as the National Agricultural Advisory Service or the National Institute of Agricultural Botany in extending experiments to different regions. There is also a range of experimental work on purely husbandry problems which is carried out by such bodies as the N.A.A.S. and the N.I.A.B.

An example of the co-operation that may develop between the research and advisory services on a husbandry problem is the work on fertilizer placement, initiated by research workers at Rothamsted. Some of this has been done with potatoes. The interest of the National Institute of Agricultural Engineering was first secured in developing a machine capable of applying fertilizer in bands to one side of and a little below the level of the seed sets. This machine was then used in field trials at many centres, with assistance from local officers of the N.A.A.S.

This work has become more important because of the change taking place from hand to machine planting. Most planting machines work on flat land, which means that the fertilizer has to be broadcast on the flat instead of, as formerly, being spread over ready-drawn drills. It was shown that fertilizer that was broadcast on the flat was only two-thirds as effective as an equal amount spread in the drills. From experiments at many centres it was concluded, that on an average placing the fertilizer in bands near, but not touching, the seed sets gave yields about three-quarters of a ton per acre more than broadcasting. It is satisfactory to record that as a result of this work an increasing number of machine planters are now being fitted with fertilizer placement attachments, though there is still room for improvement in them.

In 1948-50 the Agricultural Improvement Council arranged for a survey of maincrop potatoes, the results from which were analysed by the Statistics Department at Rothamsted³. Various papers were subsequently published discussing points of interest from this survey. It was concluded that growers' practices in regard to the standard of cultivation, manuring and quality of seed used were generally satisfactory, but that in regard to date of planting and seed rate there was room for improvement on many farms. It was estimated that in the three years of the survey about half the maincrop potato acreage of England and Wales was planted so late as to suffer appreciable loss of yield. Furthermore, Rothamsted experiments showed that responses to dung and fertilizers were all greatly reduced when planting was delayed.

The results of analysing the effect of seed rate on yield were somewhat surprising. It was estimated that the optimum rate of planting Scotch or Irish certified seed was 16-17 cwt. per acre in most areas, whereas a little over a ton per acre was generally planted. With once-grown seed, on the other hand, the optimum seed rate was estimated as over one ton per acre, whereas the average weight planted was about 17 cwt only. The explanation of the conflict between experiment and practice appeared to be due to growers usually maintaining the

same spacing between sets regardless of their size, whereas they would do better to aim at planting the optimum weight of seed per acre, spacing larger seed more widely. These conclusions have been supported by the results of several investigations on the influence of seed spacing on yield.

A second survey of maincrop potato growing is now being conducted jointly by the National Institute of Agricultural Engineering, the Potato Marketing Board and Rothamsted Experimental Station. It will be interesting to see how far the lessons of the first survey have been assimilated in practice and also how far recent advances in the harvesting and storage of potatoes, to which special attention is being paid in the second survey, are being adopted on farms.

A number of fertilizer trials are carried out each year in different parts of the country by the N.A.A.S., most of them being essentially of a local character. Occasionally more specific investigations are undertaken; for example, the needs of soils in south-east Scotland for phosphate fertilizers were investigated at the East of Scotland College of Agriculture and it was found that only 4 out of 16 soils tested were deficient in available phosphate. Rothamsted workers showed that mid-season top dressings of nitrogen fertilizer failed to prolong growth at centres in Lincolnshire where crops were considered to die down prematurely. An investigation at Wye College revealed no significant differences between the growth of potatoes given compost and artificial fertilizers, after an initial check to growth on the compost plots (due to nitrogen deficiency) had been remedied by the addition of hoof and horn manure.

A few further investigations on factors affecting yield may be mentioned. It was shown at the School of Agriculture, Sutton Bonington, that the yields of potato crops there were highly correlated with the rainfall during the months of May to September. It was shown in Scotland that within commercial varieties, there may be high and low yielding clones (strains raised from single plants), implying that selection of good clones for propagation could lead to increased yields per acre. At the Essex Institute of Agriculture a study was made of the effect of the number of sprouts per set on yield and grading of maincrop potatoes. It was found that an unnamed Northern Ireland variety benefited greatly if the sprouts were reduced to one per set but for Majestic and Ulster Supreme this treatment was unsatisfactory.

The sprouting or "chitting" of the seed of earlies is an old-established practice, but in recent years some growers have also been sprouting maincrop varieties—especially those that are to be planted last on farms with big acreages. It is now expensive to put up a glasshouse merely for chitting seed, however, and Holland has led the way in using fluorescent lights in closed houses. Lately, experiments with fluorescent lights for chitting have been made at the Terrington Experimental Husbandry Farm of the N.A.A.S. and advice has been given to growers wishing to chit seed in converted farm buildings. The desirability of painting walls and chitting boxes white to increase the amount of light reaching the seed has already been demonstrated. Another point under investigation is the length of time lighting is required in relation to the temperature.

A new method of potato planting is being investigated at the Nottingham University School of Agriculture. The sets are planted in a slight depression instead of in the traditional ridge and subsequent cultivations are shallow and merely destroy weeds and build soil around the growing plants.

An important point in potato husbandry is choice of the best variety to grow. Three varieties have retained a pre-eminent position for many years. The acreage of Majestic (put on the market in 1911) and of King Edward (1902) together account for 75 per cent of the acreage of maincrops grown in England and Wales today; and McKelvie's variety Arran Pilot (1930) still accounts for

nearly 50 per cent of the acreage of first earlies. All of these varieties, however, have their disadvantages and plant breeders, both private and official, have for many years been seeking new and improved varieties. Their productions are submitted first for Registration Trials in Scotland, which involve three years' tests against standard varieties. In recent years these trials have been extended and now include field tests in two localities in England and also laboratory tests for susceptibility to certain diseases. Varieties successfully passing the registration trials are then further tested against standard varieties at the Regional Trial Centres of the N.I.A.B. and only if they perform consistently well over a period of years are their names included in the N.I.A.B. Recommended List of potato varieties. It is disappointing that over the past thirty years or more so few varieties that have been registered in high hopes have succeeded in establishing themselves in commerce. Many have been grown to the extent of a few hundred acres and then after a few years the acreage has declined and they have ceased to be grown commercially. However, it is satisfactory to note that a number of varieties produced both by private breeders and by the Scottish Plant Breeding Station are now on the Recommended List. It is to be hoped that some of these may eventually prove themselves superior in one or other worth-while character to the three main commercial varieties of today.

MACHINERY

The most urgent problems in potato machinery research are associated with harvesting, so nearly all current work on potatoes at the National Institute of Agricultural Engineering and its Scottish sub-Station is aimed directly or indirectly at improving mechanical harvesting methods. There are two broad lines of attack: (1) improvement of present machines and methods and (2) search for an entirely new approach to potato harvesting.

The work on the improvement of present methods is directed not only towards improving harvesting equipment but also towards finding ways of planting and cultivating the growing crop that may make mechanical harvesting simpler and more efficient. For example, investigations are being made to determine how far the condition of potato seedbeds may affect harvesting operations. The indications are that a clod-free seedbed may lead to less clods at harvest time and hence to a simpler separation problem. Systems of planting in three-row beds are therefore being examined, the objects being to avoid the passage of tractor wheels over any soil which has to be lifted in harvesting and to increase the proportion of potatoes in the mixture of soil, clods and stones lifted by a harvester. Inter-row cultivation is also being studied to determine whether new equipment and techniques could reduce the number of clods present at harvest time. Thus, an exploratory trial of pre-emergence spraying for weed control has been made to find how far this may lead to a reduction in the number of cultivations needed and a reduction in the number of clods.

N.I.A.E. has now brought to an end its programme of work on a complete harvester for the grower of about 20 acres. The aim has been to find a simple machine with a low rate of wear that would work over a wider range of soil conditions than current harvesters and cause less damage to the tubers⁶. A commercially-built prototype is under trial. The possibility is also being examined of using a very simple mounted harvester with hand separation, in conjunction with a tractor capable of very low forward speeds—such as one using hydro-static transmission. A two-row experimental model has been built and is being tried in the field.

Both in Scotland and in England the greatest effort is probably being directed towards finding an efficient method of separating potatoes from clods and stones of the same size. Investigations are being made into factors governing the speed and efficiency of hand separation on conveyors, in order to improve current

harvesters, while longer-term work aims at finding some form of mechanical separation. Mechanisms which make use of differences in resilience, shape, specific gravity and surface texture are all being examined.

The alarmingly high percentage of damaged tubers resulting from current harvesting methods and the increasing interest in the washing and packaging of potatoes has called for work on tuber damage. Both laboratory and field experiments are in progress to establish the factors affecting damage and to find mechanisms and methods of handling which avoid it.

"Work study" methods are being used to find a way of increasing the efficiency of harvesting on farms using current types of machinery. Systems based on stillages or crates and other methods of handling with hand picking are being examined.

Experiments are being made with a rod weeder bar in place of a potato digger share to see if the advantages claimed for it in the U.S.A. appear under British soil conditions.

The performance of both mesh and spool graders is being examined at the N.I.A.E. Scottish Station.

At the suggestion of a private breeder, a new approach to potato harvesting is being examined which appears to offer promise. It has been known for some time that sugar beet and groundnuts can be harvested by a machine which lifts the plants by grasping the tops while the roots are loosened by a share. It has recently been demonstrated at the N.I.A.E. that a machine can harvest early potatoes in this way, provided that the tubers are firmly attached to the haulm. With this method of lifting there are no problems of soil, haulm, clod or stone separation and the tubers can be removed from the plants with no risk of damage. It cannot be used, however, with the varieties of potatoes normally grown, because they have been bred and selected to leave the haulm readily for hand harvesting; moreover, in many districts maincrops are not harvested until the haulm has died down. Nevertheless, the idea is an interesting one and there seems no reason why commercial varieties suitable for lifting by means of the haulm should not be produced. The N.I.A.E. has secured the collaboration of the Scottish Plant Breeding Station in this investigation.

POTATO BREEDING

Two research stations are concerned with potato breeding—the Scottish Plant Breeding Station and the Plant Breeding Institute at Cambridge. The former has been breeding potatoes since it was founded in 1920 and has submitted a number of new varieties for registration of which Craigs Royal, in the second early group, is perhaps the best known. The Cambridge Institute began breeding only during the war years and has not yet put any named varieties on the market. Private breeders have been active for more than half a century and during that time have produced a number of useful varieties.

For many years the main objective of breeding at the research stations was to produce a potato resistant to blight, as well as, of course, immune from wart disease. The hope was that the genes for resistance to blight present in one of the wild Central American potatoes, *Solanum demissum* (R-genes), could be transferred to the cultivated potato. That was, in fact, accomplished, but it was found that after the new resistant varieties produced had been multiplied on a field scale, they became attacked by blight—somewhat slowly at first, but later substantially. The same story was repeated several times with material patiently bred to contain one, two and even all of the four known major genes for blight resistance in *S. demissum*. It appeared that while the plant breeder was endeavouring to incorporate resistance to the known races of the blight fungus,

the fungus was at the same time producing new races capable of attacking the new varieties.

Although R-genes resistance from *S. demissum* may still be of value, these discouraging experiences have led to a re-orientation of the blight breeding programmes at both stations. Efforts are now being directed towards building up what has been termed "field resistance" by selecting or combining characters from any sources appearing to contribute towards lesser susceptibility to blight in the field. The nature of field resistance is more fully discussed in the succeeding section on potato blight.

One direction in which characters for field resistance are being sought is in the numerous wild relatives of the potato in Central and South America. The big collection of these known as the Commonwealth Potato Collection was transferred from Cambridge to the John Innes Horticultural Institution in 1955, where it continues to be available as a source of breeding material to all interested, both at home and overseas. Further material is also being sought by a University of Birmingham expedition to Mexico, where blight has long been endemic, and where useful characters contributing towards field resistance may be found. This expedition is being supported by several European organisations interested in potato breeding and material will be distributed to them subject to the usual plant quarantine restrictions.

Breeding for resistance to virus diseases also presents many difficulties. Several viruses, each quite different in nature, affect potatoes. For many years a hyper-sensitive reaction to the mosaic virus X (a virus easily transmitted by contact) has been known, which surprisingly confers field immunity on plants in which it is incorporated. The Scottish Plant Breeding Station has produced a number of varieties bearing this character and these are consequently free from the most troublesome of the various forms of potato mosaic disease. Efforts are also being made to breed for resistance to the insect-transmitted viruses leaf-roll and virus Y. Promising sources of resistance to virus Y have been found in the Commonwealth Potato Collection but so far progress with leaf-roll has been very limited.

As a result of screening tests a few years ago with material from the Commonwealth Potato Collection, some lines of *Solanum tuberosum* subsp. *andigena* were found which were resistant to infection with potato root eelworm. Breeding programmes based on this material were started in Holland, Scotland and England and some success has been achieved in combining resistance with reasonable commercial characters. As in the case of blight, however, when resistant varieties of commercial merit seemed to be in sight, it was discovered that races of potato root eelworm existed which could overcome the resistance obtained. A study was at once begun to determine the number and distribution of these resistance-breaking races, further details of which are given in the section on potato root eelworm. It may be some years yet before it is known whether the resistant types already obtained will find a useful place in the field control of this eelworm.

So far no serious breeding for resistance to potato scab has been undertaken in this country, but a start has now been made in testing a range of material from the Commonwealth Potato Collection and it is likely that some breeding work will soon be put in hand.

The failure so far to obtain satisfactory blight resistance of a permanent character and the somewhat similar difficulties encountered in breeding varieties resistant to potato root eelworm are being taken as a challenge to further effort². The number of characters of which account must be taken in potato breeding is considerable, so that the chances of obtaining those fortunate combinations on which progress depends are related to the size of the breeding

programmes. Both the Cambridge Plant Breeding Institute and the Scottish Plant Breeding Station have recently increased substantially the number of seedlings they are handling each year, and have made the further change that they are not allowing breeding for disease resistance completely to dominate the breeding programme. Efforts are now being made to produce varieties of good yield and cooking quality which may be welcomed by the industry, even though they have to be protected from diseases by traditional methods.

Besides the breeding work aimed at producing varieties of commercial merit, more fundamental studies on potato genetics are being made at the John Innes Horticultural Institution. A search is being made in the Commonwealth Potato Collection for genes for resistance to blight, virus diseases and scab; the problems of interspecific crosses are being studied; and a biochemical investigation is being made of the anthocyanin colour pigments in the flowers and tubers of a number of *Solanums*. Material obtained from difficult species crosses will be made available to potato breeders when characters of potential commercial importance are concerned.

POTATO BLIGHT

Great progress has been made in recent years in our understanding of the epidemiology of potato blight. The Conference of Advisory Plant Pathologists of the National Agricultural Advisory Service has since 1950 carried out systematic surveys of the incidence of blight on the haulm of main-crop potatoes in England and Wales each year. To develop this work the Ministry of Agriculture's Plant Pathology Laboratory secured the collaboration of the Agricultural Branch of the Meteorological Office, whose officers at weather stations in all parts of the country have reported the occurrence of the so-called Beaumont periods when temperature and humidity are such as to favour infection by the blight fungus. All data have been plotted at the Plant Pathology Laboratory on operations charts and by study of these charts in relation to the findings of the N.A.A.S. field surveys, a reliable method of regional blight forecasting has been found and put into practice. A valuable body of knowledge has also been built up on the likely incidence and development of blight in the different regions⁸.

A study has also been made of the losses caused by potato blight⁹. There is no disease which is more variable in its incidence and for which it is more difficult to make estimates of losses. After account had been taken of the damage done by spraying machines and the deleterious effect of copper sprays in dry years, an illustrative analysis by the Plant Pathology Laboratory for the ten years 1947-56 showed that in "blight" years (always years of high summer rainfall) the potential average yield of 9.6 tons per acre was reduced by blight to about 8.0 tons per acre. In years when blight was not prevalent (mainly dry years) the potential yield was of the order of 7.7 tons per acre only, which for various reasons, including damage to the haulm by unnecessary protective spraying and some end-of-season blight affecting the tubers, was reduced to 7.1 tons per acre. In spite of the blight, therefore, the total yield of sound tubers in "blight" years was usually higher than in other years.

Parallel with these studies on the incidence of blight in the country as a whole, research workers have made some detailed studies on the development of blight epidemics. The importance of infected tubers as sources from which epidemics begin each year has been confirmed both at Rothamsted and Cambridge. It was found that only a small proportion of infected tubers are able to produce an above-ground stem into which the blight fungus grows. Sporulation of the fungus on such infected stems leads to the establishment of infections on plants in the immediate vicinity. With each successive period of favourable weather a new series of infections becomes established in ever wider extent with the result that soon the immense numbers of spores produced spread the disease throughout

the crop and then to neighbouring crops in which there may be no primary infection centres. At the former Potato Genetics Station and at the Botany School, Cambridge, it was shown that in dry conditions the blight fungus may remain viable for weeks in stem lesions and then sporulate as soon as moist conditions supervene.

The breakdown of resistance in a number of varieties bred specifically for blight resistance focused attention on the physiological races of blight and considerable work has been done on these at the Scottish Plant Breeding Station. Four major genes governing resistance to blight have been identified in the wild potato *Solanum demissum*, which was used as the resistant parent in the breeding work. The progeny of crosses with this have provided the means of separating and identifying various races of blight and a scheme of naming these, proposed by the workers in Scotland, has been accepted for international use. It is of interest that the race of blight most prevalent on commercial potatoes, which before 1950 was race 0, is now race 4, not only in this country but also in a number of other potato-growing countries.

It has been mentioned already that because of the breakdown of R-gene resistance, effort is now being devoted to finding and combining characters that may contribute to what is called "field resistance". The nature of field resistance is being studied at Rothamsted where careful comparisons have been made of varieties said to differ in this respect. Two differences that have been established are in the incidence of lesions on stems and petioles and in the extent of fungus sporulation on lesions on different varieties. The former could depend on differences in growth habit giving rise to differences in microclimate in the crop—e.g. the length of time water was held in the axils of leaves. Differences in spore production on different varieties probably depend more on internal characters, but obviously any substantial differences of this nature could soon lead to marked differences in the incidence of disease after several generations of fungus reproduction. The search for new breeding material with characters contributing to field resistance, by an expedition to Mexico, has already been described.

Experimental work on control measures has been carried out over a series of years by the N.A.A.S. The most extensive trials have been those at Terrington in the Eastern Province, where comparisons have been made between wet spraying, atomizing, dry dusting, and low volume spraying from above only. The effect of the treatments was to increase the yield in blight years by prolonging the growth of the haulm; to decrease the yield (about 4 per cent per acre) in all years by wheel damage; and to decrease the yield in dry years due to the toxic effects of copper sprays. It appeared that only about three years in ten could be expected to be severe blight years, with the disease reaching the stage of 75 per cent destruction of foliage by mid-August and with a probable gain from efficient spraying of 2-3 tons per acre; in two years out of ten, blight could be expected to reach the 75 per cent stage by the end of August, with probable net gain from spraying of about one ton per acre; and in another two years in ten, when blight would not be expected to reach the 75 per cent stage till mid-September, any possible small gain from spraying would be lost by wheel damage. In the remaining three years of a ten year period, no blight at all would be expected, and in these years there could be a substantial loss from spraying, due to wheel damage and phytotoxic effects. In the trials, wet sprays prove generally superior to dusts. Trials in the West Midlands and Yorkshire showed that in most areas routine spraying against blight could scarcely be justified from its economic returns. Results in other districts conformed to the expected pattern. In the southern half of the country and in coastal districts, where blight appears earlier, the proportion of years in which spraying could be expected to give worthwhile results would be higher.

The exceptionally wet summer of 1958 provided a severe test for control recommendations. On many farms it was not possible to take spraying machines on to the land at the times when spraying was most needed. Application of sprays by aircraft, which incidentally spares the damage from wheel injury, was widely resorted to and many thousands of acres of potatoes in the main ware growing districts were sprayed in this way. Continuous wet weather so favoured the development of blight, however, and so reduced retention of the fungicide in the sprays that even several sprayings by aircraft were unable to prolong the growth of the plants much more than a week or so. Although the use of aircraft for potato spraying is likely to increase in the ware growing districts of Lincolnshire and the Isle of Ely, its future elsewhere is still uncertain. Much will depend on whether there is enough other work for the aircraft in years when blight is not prevalent to justify the maintenance of a sufficient fleet to be effective in bad blight years.

Other points on which more investigations are needed are the practicability of eliminating primary infections at an early stage and the relative merits of non-copper and copper-containing sprays.

POTATO VIRUS DISEASES

The chief advances in potato virus research have been in epidemiology, application of serological techniques in certification schemes, control of leaf-roll by insecticides applied to ware crops and in freeing plants from infection.

War-time work from Rothamsted on the spread of virus diseases in ware-growing districts had shown that roguing alone was of no value as a practical control measure. This was because viruses were so often spread from infected plants by flying aphids at a very early stage, before such plants could be identified and removed. Studies of aphid behaviour and dispersal confirmed the importance of winged aphids in spreading leaf-roll and Y virus; they also showed that the numbers of winged aphids caught on sticky traps bore a much closer relationship to virus spread than did the total numbers of wingless aphids on the plants, formerly used as the best criterion of the danger of virus spread.

The Ministry of Agriculture's Plant Pathology Laboratory applied this new knowledge in an investigation of aphid movement and spread of viruses in the seed-growing areas of England and Wales⁷. It was concluded that in spite of the many variables concerned, aphid data collected as recommended could provide a fairly reliable indication of potential virus spread and thus of the suitability of a district for the raising of seed potatoes.

A collaborative study between workers at Rothamsted and Sutton Bonington on the effect of date of planting and harvesting potatoes on virus infection and yield established that summer planting for the production of healthy seed, as practised in some warmer climates, is of no value in this country.

The insect-borne viruses, leaf-roll and Y, are not the only ones important in seed certification schemes. Virus X, which seems to be spread mainly by contact between infected and healthy plants or by other mechanical means, is of almost equal importance. A number of studies have been made on its dissemination and stocks free from it have been propagated from single tested tubers. These stocks form the basis of a new class of "virus-tested" seed in the Scottish certification scheme and it is of interest that serological methods of detecting infected plants, first developed in England but later adapted and applied on a large scale in Holland and elsewhere, are now generally used in testing this material.

Three further virus troubles that have been recognised only in recent years are virus S, veinal necrosis and a disease caused by certain soil-borne viruses. Virus S, which was first recognised in Holland, has been found to be widespread in many British varieties. The disease it causes is not a serious one, but as it

reduces yield efforts are being made to eliminate it from stocks of new varieties. Veinal necrosis, a strain of virus Y, also difficult to detect in the field, has been found mainly in the variety *Craigs Royal* and special measures are being taken to control it. Lastly, soil-borne viruses of the ringspot type have been found in potatoes, but much work remains to be done on these before it will be possible to estimate their economic significance.

The cost of seed is a major item in potato growing and the epidemiological investigations mentioned earlier were begun with a view to finding some way of prolonging the useful life of seed in England. Controlling the aphid vectors seems an obvious approach but early attempts to do so by spraying or fumigating with nicotine gave little promise of successful commercial application. When the persistent insecticide DDT and the systemic organophosphorus insecticides were developed, however, a new attack on the problem became possible and workers at Rothamsted⁴ have shown that the useful life of food potato stocks could be prolonged for several years in England by periodic spraying with these insecticides. These insecticides are more effective in controlling leaf-roll than rugose mosaic (the disease caused by virus Y) because aphids cannot pick up the leaf-roll virus and become infective in less than a day, during which time they die if the plants have been treated with insecticide; on the other hand, aphids can acquire virus Y and transmit it to healthy plants within a few minutes, before they can be affected by any insecticide. As no existing insecticide kills immediately, aphids that are already infective when they arrive on a sprayed crop can transmit either virus before they are killed. The investigations on control by spraying are being continued with the co-operation of the N.A.A.S. and private farmers, to determine the economics of the method. It seems certain that in future new seed stocks of good quality will not have to be discarded every year as has so often been done in the past.

An important advance is the development of methods for freeing systemically infected plants from certain viruses, which make it possible to regenerate healthy clones of varieties that have become completely infected. Two methods have been successfully used at Rothamsted: heat therapy and the raising of plants from excised shoot tips. As to the first, tubers infected with leaf-roll virus and kept at 37.5° C. in a humid atmosphere for 25 days produced healthy plants. As to the second, plants of the varieties *King Edward* and *Arran Victory*, all stocks of which contain paracrinkle or virus S, were obtained free from this virus by culturing excised meristems. These techniques have no application on a large scale but they give promise that, in the future, varieties need not be discarded simply because they have become virus infected.

POTATO ROOT EELWORM

Ten years ago an estimate was made by the Plant Pathology Laboratory of the direct annual losses due to potato root eelworm on farms and a figure of 200,000 tons of potatoes worth about £2,000,000 was obtained. Since that time losses have diminished, owing to wider use by farmers of the soil sampling service of the N.A.A.S., which provides an estimate of the cyst content of soils before planting. However, this diminution of direct losses due to the pest can be no excuse for the adoption of a complacent attitude. At present farmers are avoiding serious losses simply by planting other fields when they receive reports of too heavy an infestation on the one they first intended to plant. As a result it is now becoming increasingly difficult to find fields in the main potato areas where eelworm is not present in some degree. There is thus a real danger that high populations will eventually build up on most land suitable for potatoes, unless rotations can be lengthened substantially.

Because of the serious nature of the pest, a great deal of research has been done on it since the war. There have been a number of studies on the general

biology of the eelworm, mainly at Rothamsted and the University of Durham. These have enlarged our knowledge of such matters as host range, factors affecting the hatching of the cysts, movement of eelworms in the soil and penetration and development in potato roots.

Studies have also been made on the substance excreted from potato roots (the "hatching factor" or "root diffusate") which stimulates hatching of the cysts. Attempts have been made to use this both naturally and artificially. As an example of the former, tests were made to see whether black nightshade, a weed allied to the potato which is known to produce hatching factor, but on which the eelworms do not multiply, would, when grown either alone or under oats, appreciably reduce the viable cyst content of infested soils. However, the tests showed that the growing of this plant did not effect a sufficient reduction of cysts to make it economically worthwhile.

A substantially greater effort was put into an attempt to isolate the hatching factor and identify it chemically. This work was begun by the Chemical Laboratory at Cambridge, which secured the collaboration of the Experimental Station at Cheshunt and later the Horticultural Department of the University of Reading and Rothamsted Experimental Station. Potato and tomato plants, both of which are good sources of the factor, were grown in sand or gravel culture and the roots periodically leached with water. The hatching factor was then extracted from the leachate either with activated carbon or by vacuum concentration and subsequent solvent extraction. Purification from extraneous matter presented difficulties, but a somewhat waxy product of high activity was eventually obtained. It was not possible to identify fully the active constituent, which was named eclepic acid, but a certain amount of information about its chemical structure was obtained. It was considered to have a lactone structure and to be free from nitrogen. A series of possibly related compounds was also prepared, of which anhydrotetrone acid was the only one which showed appreciable hatching activity.

It was hoped that if the hatching factor could be synthesized, it might be possible to use it for applying to eelworm infested potato fields when no potatoes were growing and so bring about a substantial reduction in the number of viable cysts. However, it would be a major problem to bring any such substance in contact with cysts at the depths at which many of them occur. Work at Rothamsted, moreover, has shown that the hatching factor is not stable in soil and soon disappears, so for the present this work is not being actively pursued.

Experiments have been made with a number of chemicals that might be used to kill nematodes in the soil (nematicides), but so far none has been found that is cheap enough to use on the extensive field scale required. However, a useful method of treating glasshouse soils by combining fumigation with DDT with the application of a water-based seal of solubilized xyleneol was worked out by the National Agricultural Advisory Service at Bristol. Experiments with other chemicals that may be applied economically to valuable early potato land and on machinery for their application are in progress at the West of Scotland Agricultural College. Further work on nematicides is also planned at Rothamsted.

A serious difficulty that is often not fully appreciated is the perpetuation of root eelworm, in the years when land is not being cropped with potatoes, on the roots of "volunteer" potato plants or "groundkeepers". Counts have shown that there may be as many as from five to ten thousand groundkeepers per acre in a cereal crop following potatoes and that even two or three years afterwards the numbers may still be in the hundreds. Efforts are being made to find a chemical spray that would kill these groundkeepers without harming other crops in which they may be growing.

Hopes of achieving a practical control of potato root eelworm have recently turned towards the breeding of resistant varieties, as already described in the section on breeding. It was therefore a major disappointment when populations of eelworm were found that were capable of attacking these supposedly resistant varieties⁵. Efforts are now being made to find out as much as possible about the distribution of these resistance-breaking biotypes of the eelworm and also the possible genetic behaviour of the character of "aggressiveness". Unfortunately, biotypes that will attack the resistant plants so far bred are fairly widespread, but it is too soon yet to say whether or not there are areas where resistant plants might usefully be grown. As it has been shown that the resistant plants produce a hatching factor and that their roots may be fairly heavily invaded by eelworms, the females of which in most cases fail to develop into fully grown cysts, one way in which resistant varieties could be used would be as a "trap crop", to induce the hatching of cysts without the usual production of a new crop of cysts to increase soil infestation.

It is likely to be several years yet before the outcome of these efforts to breed varieties resistant to potato root eelworm is known. Meanwhile the breeding work and the investigations on eelworm biotypes are both being pressed ahead with vigour.

At the same time the agricultural departments are doing everything possible to assist control of potato root eelworm by administrative measures. Besides the soil sampling service for farmers, run by the N.A.A.S., the various departments issuing certificates for the health of seed potatoes now demand a pre-cropping soil test for freedom from root eelworm of all fields on which Foundation Seed or Stock Seed is to be grown, and also freedom from obvious cysts for all certified seed. In special circumstances, potatoes grown on infested soil in Scotland may be washed free from soil and cysts in an approved manner.

OTHER DISEASES

Of the many other diseases affecting potatoes, those on which most work has been done in recent years are bacterial rots, dry rot, gangrene, scab and skin spot.

Bacterial rots are of practical importance in connection with the transport of seed potatoes and also in potato clamps or stores if the tubers become wet or overheat. Studies on the conditions favouring bacterial infection have been made in the Botany School at Cambridge, at the Imperial College, and by the former Potato Storage Investigation team at Sutton Bonington. It has been shown that several kinds of bacteria may be involved and that infection is favoured by free moisture on the tubers. Infection arising in this way and also bacterial invasion following potato blight often cause a rise in temperature and increased production of carbon dioxide, which in confined spaces such as stores or sheeted railway trucks may greatly accelerate rotting and lead to total spoilage.

These findings were strikingly confirmed when a machinery firm, in an effort to separate potatoes from clods and stones in a new pattern of harvester, passed the potatoes through a sludge tank and subsequent water spray. Although an excellent separation was obtained, it was found to be impossible to dry the potatoes sufficiently, even on sponge rubber rollers, to make it safe to put them in clamp or store. In almost every test serious bacterial rots developed and made the stored potatoes a total loss. A similar problem, though on a smaller scale, faced those washing potatoes for pre-packaging. Here again there were losses from wet rots, but the need for thorough drying of the tubers is now generally recognised.

☛ Closely related to the bacteria causing wet rots is the organism responsible for the black leg disease of potatoes in the field. Because of its importance in

seed potato certification this has been studied by the Potato Storage Investigation team at Sutton Bonington and also by the Plant Pathology Laboratory of the Department of Agriculture for Scotland. The research at Sutton Bonington (and subsequently at Aberdeen) suggests that, besides the well-known black leg disease, there is a bacterial rot of potato stems prevalent later in the season which is due to types of pectolytic bacteria other than the generally accepted black leg organism.

Dry rot, which is most troublesome as a disease of seed potatoes, was investigated over a period of years by the team at Sutton Bonington, working in conjunction with the Plant Pathology Laboratory of the Department of Agriculture for Scotland. It was shown that the dry rot fungus was present in differing amounts in different soils; also, that most infection occurred at riddling time through minute skin wounds caused by the wires of the reciprocating riddles on grading machines. Although the results of this work have led to a greater appreciation of the need for careful handling of the seed of susceptible varieties, so far no reasonably cheap machine for grading potatoes without the reciprocating wire riddle has been developed here. Nor has any fully satisfactory method of chemical disinfection of seed tubers been devised. Dust treatments with tetrachloronitrobenzene, although giving fair control of dry rot, may at times cause delay in sprouting. The most promising treatment at present is to dip the tubers immediately on lifting in a mercurial fungicide, but few growers are able to ensure the necessary subsequent drying. However, one plant for doing this on a substantial scale is in successful operation in Scotland.

Gangrene is a disease of seed tubers very similar to dry rot, but caused by a different fungus (*Phoma* spp.). It is now being studied both at Aberdeen and at the Plant Pathology Laboratory of the Department of Agriculture for Scotland. The causal fungus lives in the soil and establishes itself on the stems and tubers at quite an early stage in growth, though visible signs of it do not appear until the stems become senescent and the tubers are in storage. The increased incidence of the disease in parts of north Scotland in recent years has been attributed to damage to the tubers caused by elevator harvesters working on stony soils and to the cold, draughty conditions in many potato stores. In the investigations at Aberdeen, attention is being paid to control both through crop management and chemical treatment of the tubers.

A survey of Common Scab on potatoes made in 1952 and 1953 by the Plant Pathology Laboratory in collaboration with the Potato Division of the Ministry of Food showed that in a dry year some 4 per cent of the national potato yield was substantially affected with scab and in a cool, moist year some 2 per cent¹⁰. The incidence of the disease was highest in parts of Yorkshire and the Midlands and not in the main ware-growing areas. The survey confirmed past experience that scab tends to be worst on light sandy or gravelly soils and on land recently ploughed up from grass.

A study of strains of the *Streptomyces* causing scab, made by the Potato Storage Investigation team at Sutton Bonington, showed that these varied greatly in virulence, but no evidence of physiological specialization in relation to host variety was found. Tests with virulent strains were made on a range of varieties, including some scab-resistant ones from America and Germany, and on a number of lines of the South American *Solanum tuberosum* subsp. *andigena* that seemed as if they might be of value in breeding for scab resistance. This work is being continued at the John Innes Horticultural Institution.

Skin spot is a disease causing relatively inconspicuous pustules on the tubers, but when the eyes of seed potatoes are affected, sprout emergence and plant stand may be markedly reduced. This disease has recently been studied both in Edinburgh and at Rothamsted. Infection is favoured by cool, moist conditions.

The incidence of the disease may be reduced by cutting the haulm from 2 to 4 weeks before lifting, by certain mercurial dips, and by storing the tubers in boxes instead of in pits.

STORAGE

Important changes have been taking place in recent years in methods of handling and storing potatoes. The change from storing in the traditional clamps or pits began in Scotland early in the war years, when seed growers found that working conditions for dressing and bagging the seed before despatch were greatly improved if the potatoes were stored in bulk in a shed. Also, during the war years, some growers of ware potatoes in England began storing in bulk between straw bales, either in the open or in a Dutch barn. There were, however, manifest dangers besides advantages in these developments and, with the object of working out the proper conditions for storing potatoes in bulk in buildings, a collaborative investigation was arranged between the Department of Scientific and Industrial Research and the Agricultural Research Council.

A mission was first sent to the United States to examine potato storage practice there, which for climatic reasons has always been based on specially constructed stores. On the return of this mission, apparatus for studying temperature and air movement in bulked potatoes under English conditions was set up at the Ditton Laboratory of the Department of Scientific and Industrial Research, and an experimental commercial store was built by the Agricultural Research Council at the Nottingham University School of Agriculture for a study of handling techniques, ventilation and store management.

The results of the two investigations established the main requirements for successful indoor storage in Great Britain and these were published in a leaflet issued by the Ministry of Agriculture and Fisheries¹¹. A bulletin with more detailed information has also been prepared and is expected to be published shortly. At the same time, the Ministry's Agricultural Land Service has arranged many meetings for farmers at which the principles of good storage in buildings have been described and demonstrated. Already some hundreds of farmers have either built new potato stores or converted farm buildings for the purpose and there seems little doubt that many more will do so in the coming years.

Reference has already been made under the heading Diseases to some investigations on the dangers of storing wet potatoes. A further problem arising in both clamp and indoor storage is the prevention of sprouting in tubers stored beyond March. A number of chemicals have been tested in an effort to find one suitable for use as a commercial sprout depressant. The latest and so far the most promising is nonyl alcohol, which, however, is only suitable for use in stores. The vapour is blown into the stack by way of the ventilation system or special distribution pipes. This development is an outcome of research at the Ditton Laboratory on the effect of various volatile substances on sprouting.

The Ditton Laboratory has also investigated, in conjunction with the Atomic Energy Research Establishment at Harwell, the prevention of sprouting by means of irradiation. Although very effective sprout inhibition has been obtained, there have been undesirable effects on the keeping quality of the tubers. Much further work will be needed before it can be decided whether this method of sprout suppression has a commercial future.

The final phase in the handling of the potato crop is its distribution for retail sale and here the introduction of pre-packaging may have some important repercussions on the growing of the crop. As the preparation of potatoes for pre-packs usually involves washing, precautions must be taken against the development of wet rots. Another effect of washing is to reveal blemishes due to mechanical damage, scab and other diseases. There must thus inevitably be

increasing interest in the avoidance of tuber blemishes during the growing and handling of the crop. Special studies have already been started by the National Institute of Agricultural Engineering to estimate the damage sustained by tubers at various stages during and after harvesting.

QUALITY

The consumer is the ultimate judge of quality and until he is satisfied there is no reason for those concerned with production and distribution to be satisfied. Complaints about the poor "quality" of potatoes are not infrequent nowadays, but the position is confused because users often do not distinguish between such varied causes as mechanical damage, disease, and poor cooking quality. It is quite likely, indeed, that the bulk of complaints relate to mechanical damage and disease, which are not aspects of quality in the strict sense and which are dealt with under other headings.

The blackening of potatoes after cooking has been a subject of investigation for very many years and in several countries and there seems little doubt that it has more than one cause. For example, there is ample experimental evidence that a deficiency of potassium, or a high nitrogen potassium ratio, may give rise to it, but there is also evidence that it may be correlated with a high content of iron, or of phenolic substances in the tubers, or with the degree of acidity of the tubers. Taking account also of varietal differences and differences in climate, soil type and fertilizer treatment, it is scarcely surprising that no one cause or cure has been found.

The work done at Long Ashton Research Station towards the end of the war showed that on poor sites fertilizers usually had little effect on blackening, whereas on better sites potash and phosphate often improved both colour and texture. Since that time a series of fertilizer experiments on potatoes has been laid down on the N.A.A.S. Experimental Husbandry Farms and the produce from these, as well as from Regional Trial Centres of the National Institute of Agricultural Botany, has been tested for cooking quality at the Institute. The Institute has also collaborated with the Low Temperature Research Station in an investigation of the biochemistry of after-cooking discoloration in potatoes. In this it was shown¹ that the distribution of blackening in individual cooked tubers is governed mainly by two factors interacting: the competition for iron of the chlorogenic acid group of phenols and citric acid. The biochemical studies on which these findings were based have made useful additions to our knowledge of the chemical changes occurring during the development of potato tubers. Further valuable work on the nutrition of potatoes in relation to their physiology has been done in Holland.

In America potatoes are often graded by floating in brine solutions of different strengths to separate them into categories considered suitable for boiling, baking and frying. So far nothing similar has been done on any scale in this country, apart from some war-time work which was part of a programme on vegetable dehydration. However, investigations are now being undertaken at the N.I.A.B. on the influence on the texture of the cooked potato of the content of total solids of the individual tubers as determined by flotation methods. Results with recently introduced British varieties suggest that there is considerable variability in the total solid content between individual tubers of the same variety, even when grown in the same district. Still greater differences have been demonstrated between such tubers when grown in different districts and between tubers of different varieties.

Varieties in N.I.A.B. trials are examined for flavour, discoloration before and after cooking, specific gravity and texture. In co-operation with processing organizations and a large catering firm, varieties are tested under commercial

processing conditions for boiling, chipping, and crisping. Registration trials for new varieties include tasting panel tests and some varieties are fried.

It is known that the colour of chips and crisps is markedly affected by the sweetening that occurs as the temperature of potatoes drops below 45°F. After winter storage, therefore, a period of conditioning at a higher temperature is often needed before potatoes can be used for these purposes. Even so, the de-sweetening is usually uneven and the resulting product is seldom satisfactory. It is known also that different samples of potato differ in their rates of sweetening and de-sweetening. Some work on this has been done at the Experimental Factory of the Ministry of Agriculture, Fisheries and Food at Aberdeen, at the Ditton Laboratory of the D.S.I.R., and elsewhere, but there is obviously opportunity for further study of the sugar content and dry-matter of English varieties as affected by growing, harvesting and storage conditions.

Besides these particular aspects of quality, there are certain others, such as ascorbic acid (vitamin C) content, protein content, and cell size on which work has been done. As implied in the section on breeding, the need now is for some way of integrating these various factors to give a measure of what the consumer recognizes as good or poor quality. There seems no reason why more intensive work should not enable research workers eventually to define more accurately than is possible today the rather subjective and elusive term "quality". If this were possible it would be of great assistance to the potato breeder.

CONCLUSION

It is obvious from this review that advances in potato research are being made on a wide front. This is largely because the work is being undertaken at many centres. It seems likely that future research, besides developing further in the directions already described, will devote more effort to fundamental work on the physiology of growth. At the other end of the research scale there are many opportunities for research workers to study, in collaboration with advisory officers, the application of research results in practice.

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SOME RECENT DEVELOPMENTS IN THE IMMUNISATION OF CATTLE AGAINST HUSK

The control of parasitic disease is of major importance to the stock farmer for three main reasons: there is a recurring cost from abnormalities due to a reduced growth rate and poor utilisation of food; certain diseases such as parasitic bronchitis and *Nematodirus* infection cause a heavy mortality; the enhanced nutritive value of pasture produced by modern methods of management cannot be fully utilised because concentrated stocking leads to a high parasitic burden and consequently to diminished efficiency. The main methods of control have been by the use of anthelmintics—drugs acting upon helminth parasites—and by routines of grazing management designed to reduce infection rates to a minimum. These methods have been highly successful against certain parasites and have been completely inadequate in others. Apart from the obvious fact that there are parasites against which all known anthelmintics are inactive, there are several diseases in which a great deal of damage is done by immature parasites which may be inaccessible to treatment. Examples of parasitic diseases not easily amenable to treatment are parasitic bronchitis, ostertagiasis and ovine nematodiriasis. In other conditions, such as hookworm infections and haemonchosis, a great deal of damage is done before gross outward symptoms of illness indicate the need for treatment.

Vaccines and antisera have been widely used against viral and bacterial infections, but they have not been applied to parasitic disease in spite of the fact that it has been known for some time that high degrees of resistance to reinfection can be acquired in many helminth diseases. Indeed, with certain worm infections, it has been shown that the injection of serum from immune animals into susceptible animals confers a passive immunity on the latter¹.

All the work on artificially immunising animals against helminth disease has been carried out on a laboratory scale, and, in the main, small rodents have been chosen as hosts. In 1952, at the University of Glasgow Veterinary School, a programme of work was started on *Dictyocaulus viviparus* infections using the natural host—cattle—in an attempt to produce a practical method of immunising against parasitic bronchitis under field conditions. It is well established that a strong immunity to this infection can be acquired under field conditions and that a single experimental infection confers a degree of resistance^{2,3,4,5}.

We shall first describe experiments in which antiserum from artificially immunised animals was injected into normal animals ("passive immunity"), and then attempts to produce "active immunity" by injecting animals with various preparations of dead parasites.

PASSIVE IMMUNITY

The first step in our experiments on passive immunity against parasitic bronchitis was to develop a method of assessing the magnitude of the response to infection in terms of the concentration of antibodies present in the blood of infected animals. For this purpose we used a quantitative "complement fixation" test which enabled us to follow the rise and fall of the concentration of antibodies quite accurately⁵.

Applying this test to animals infected with *D. viviparus*, we found that the antibody titre rose relatively slowly and reached a maximum at about 100 days after infection; it then fell away⁵. On subsequent reinfection a much quicker response occurred and high concentrations of antibody were attained in 14 days. This "secondary response" was repeated on subsequent reinfections. The response to parasitic infection, then, appeared to follow the orthodox and well-established pattern of responses to bacteria and to foreign chemical compounds.

Several cows were repeatedly immunised in this way and blood was withdrawn at the time when the concentration of antibodies was at its peak. Serum was prepared from the blood and then pooled; from this serum we prepared the particular protein fraction in which antibodies are concentrated, and this was injected into the abdominal cavities of a group of susceptible calves. Antibodies revealed by the complement fixation test appeared promptly in their own blood⁶. These calves, and an untreated group, were then challenged with a standard dose of larvae and all were killed 30 days later, the time at which parasitic infestation of the lungs reaches its height. By counting the worms in the lungs of the immunised and the non-immunised groups we were able to show that a high degree of resistance had been transmitted to the serum-treated calves.

ACTIVE IMMUNISATION BY PREPARATIONS FROM DEAD PARASITES

Various attempts were then made to obtain active immunity in calves by injecting preparations of adult worms. The most successful of these was a vaccine composed of ground-up whole worms which had been dried in the frozen state and then mixed with a substance (Freund's adjuvant) known to enhance immunological reactions of many kinds. This produced a response capable of reducing the "take" of experimental infections by about 50 per cent under a wide variety of different exposures to infection^{4,7}. Although these results are academically interesting in demonstrating that active artificial immunity is indeed possible, there are two reasons why a field vaccine of this type is not likely to be of practical value. The first is that calves have to be infected and killed in order to obtain the lungworms from which the vaccine is made; the amount that can be obtained from each calf is small, and the resulting product is therefore very costly. The second is that a high degree of immunity is required if immunisation is to be really effective. In a feebly immune animal a proportion of the infecting larvae manage to pass the usual defence barrier provided by the mesenteric nodes, and proceed to the lungs where they finally succumb to the antibody attack. Here the dead parasites provoke a particularly severe reaction from the tissues of the host, and the damage so produced is actually greater than that which would have been caused by the same number of living larvae. In parasites with a migratory cycle like that of *D. viviparus*, immunity, to be valuable, has therefore to be almost of the "all or nothing" category.

THE NATURE OF THE SUBSTANCES THAT PROVOKE IMMUNITY AGAINST HELMINTH PARASITES

It was thought that one reason for the failure of our "dead" preparations to produce a high level of immunity was that the defensive reaction might depend partly on substances that would be produced only by living worms. Thorson, for example, has shown that the fluid in which infective larvae of *Nippostrongylus muris* are stored is better able to excite immunity than the killed larvae themselves, and he has begun to try to identify the substances involved⁸. The actual mechanism by which the development or migration of larvae is halted is still obscure, but one possible interpretation of recent work is that the antibodies act, in part, by stopping the action of the ferments produced by living larvae which break down the connective tissues and so make it possible for the larvae to migrate. In the reaction against larvae, there is a cellular reaction as well as a production of antibodies in the blood. It is not yet clear what part this cellular reaction plays; it may kill the larvae, or may act on larvae which have already been slowed down by antibodies, or may merely be a scavenging process.

Whatever the basic mechanism involved, it became obvious that in parasitic bronchitis the mesenteric nodes—the lymph glands in the folds of connecting tissue supporting the viscera—were the place where most larvae are killed in the immune host.

The factors discussed above led to the general thesis that an efficient vaccine should have two main features: (i) it should contain substances produced by living lung larvae, and (ii) it should stimulate the antibody-forming tissue at the natural site, viz. the mesenteric nodes. One obvious solution of this problem is the use of partially inactivated larvae, i.e. larvae which will migrate as far as the mesenteric nodes and there die, thus stimulating immunity but not proceeding to the lungs stage in their life cycle at which their harmful effects are exerted.

PARTIAL INACTIVATION BY X-IRRADIATION]

The method which has been used to inactivate larvae is X-irradiation. It has been known for 40 years that X-rays have a deleterious effect on *Trichinella spiralis* larvae encysted in pork, and X-irradiation has been suggested as a method of "sterilising" measly pork. In investigating this possibility, two groups of American workers found that if infective *T. spiralis* larvae were irradiated, the resulting adult infections were largely sterile^{9,10}. These sterile infections produced a certain degree of resistance to reinfection, but it was also shown that the acquired immunity was dependent upon an infestation by adults and that if the doses of X-rays were high enough to prevent the larvae becoming adult, then no immunity resulted.

Fortunately this dependence upon infection by adults did not prove to be true of *D. viviparus*. Experiments were carried out in which calves were given doses of normal larvae and of larvae which had been treated with 20,000, 40,000 and 60,000 roentgens of X-irradiation^{4,11,12}. Half the calves in each group were killed after 30 days to see how many worms would mature from the irradiated infective larvae. In the 20,000 and 40,000 roentgen groups it was found that very small numbers of larvae progressed further than the mesenteric nodes (an average of two as compared with an average of 1,000 in the control group): none was found in the 60,000 roentgen group.

The calves in the remaining half of each group were challenged with less than a killing dose of normal larvae. Untreated animals had a mean "take" of about 1,000 worms. The 60,000 roentgen group was similar, and the obvious interpretation of this lack of immunity was that this high dose of irradiation had completely inactivated the larvae which were then unable to penetrate to the mesenteric lymph nodes and so stimulate immunity. The calves in the 20,000 and 40,000 roentgen groups had a mean take of only 12 worms, a reduction in worm burden of 99 per cent.

As a safety precaution the upper levels of irradiation (40,000 and 50,000 roentgens), at which larvae still remain capable of provoking a defence reaction, were used in all subsequent experiments. The dose of normal larvae used as a standard challenge (4,000) is that dose which will produce symptoms as severe as those in a field case, and which will confer a strong immunity on recovery. The same dose of inactivated larvae was therefore used in our first experiments and the degree of resistance induced was found to be similar to that produced by the same number of healthy larvae. As a further safety measure the immunising dose was reduced from 4,000 to 1,000 larvae for field use, since any failure of inactivation would not then result in severe disease. Animals treated with this smaller number of irradiated larvae showed a reduced but still acceptable degree of resistance.

PRELIMINARY FIELD TRIALS OF *D. viviparus* VACCINE

In 1957 two field trials were carried out^{11,13}. The first involved 1,000 calves on 40 commercial farms which had a history of severe parasitic bronchitis. Half the calves on each farm were vaccinated, the remainder acting as controls; there was no interference with routine farm management. Samples of faeces

from each of the 1,000 calves were examined monthly from March until November, and no failures of larval inactivation were found. In the final analysis it was found that the disease occurred in 62 per cent of the control calves coming under challenge and in only 6 per cent of the vaccinated calves.

The second trial was carried out on a three-acre pasture. Fifteen calves heavily infected with parasitic bronchitis were allowed to graze the pasture until the grass was heavily contaminated with larvae. Fifteen vaccinated animals and twelve controls were then put on to this field. Ten controls (83 per cent) and three vaccinates (20 per cent) died under these severe conditions. The output of larvae in the faeces at its peak averaged 700/gm. in the controls and only 200/gm. in the vaccinates, and there was always a difference of at least 20 per minute in the respiratory rates of the two groups. This demonstrated not only that the clinical disease and the mortality were considerably modified by vaccination, but also that the contamination of the pasture was markedly reduced.

DOUBLE VACCINATION

The effect of two successive doses of the vaccine was then studied to see if a solid immunity could be produced against challenge by larger numbers of living larvae¹⁴. Three groups of ten calves were given an initial dose of 1,000 irradiated larvae and after six weeks the groups received a second dose of 1,000, 2,000 and 4,000 irradiated larvae respectively. These calves, together with controls, were then challenged with 10,000 larvae ($2\frac{1}{2}$ times the earlier challenge level). The control calves became severely ill and were killed; a mean burden of 700 adult and a large, but uncountable, number of immature worms were found in their lungs. Throughout the experiment the vaccinated animals were clinically normal and worms were completely absent from their lungs at slaughter. This very high level of protection seemed likely to be able to control the majority of field outbreaks.

APPLICATION TO THE FIELD

In the experiments described above the numbers of animals vaccinated were relatively small, the largest batch of vaccine prepared at any one time being only in the region of 500 doses. The quantity of larvae required could thus be cultured on a laboratory scale. Considerable work was involved in scaling up the process for possible commercial production, and good progress has been made towards solving the problems of large scale culture. We are now attempting to prolong the period during which the vaccine remains active.

In 1958 a much larger trial was carried out. This was designed largely to test two factors: (i) the safety of the vaccine under a wide range of farm conditions, and (ii) the practicability of factory production, packing, transport, etc. Veterinary surgeons from Aberdeenshire to Wigtown co-operated in the trial and supplied a list of farms, of all management types, on which parasitic bronchitis was a serious problem. Finally, over 8,000 calves on 200 farms were vaccinated. These were given two doses a month apart and were visited regularly throughout the summer. The vaccine appeared completely safe and the packaging and transport had no markedly deleterious effect. Despite the fact that 1958 was a very bad year for parasitic bronchitis there was no single breakdown of immunity among the calves which had been vaccinated twice before being exposed to challenge. The incorporation in this trial of an equal number of untreated controls was impossible, but on several farms deaths from the disease occurred in unvaccinated stock and in most places neighbouring farms were badly affected. The trial was, however, concerned more with the safety of the vaccine than with a statistical test of its power to elicit resistance, although it appeared obvious that the disease was being prevented by the vaccine. Many of the farms were free of parasitic bronchitis for the first time for many years. Quite apart

from the drop in disease and mortality, the farmers reported much reduced feeding bills as supplementary feeding had been cut, calves did not have to be reared or removed indoors, and animals could be left longer at pasture than in previous years.

It appears possible, then, that this type of vaccination could be used as a practical measure against the disease under commercial farming conditions.

APPLICATION TO OTHER PARASITIC DISEASES

At the moment it appears that inactivated larvae can produce immunity in a number of other helminth infections. For example, in experiments with *Haemonchus contortus* in sheep a single dose of vaccine has reduced the take from 2,000 (in controls) to 0¹⁵. This is a parasite with a very restricted migration, yet the larvae seem able to induce immunity. In hookworm infections (*Unicinaria stenocephala*) in dogs, irradiated larvae also produce a very good immunity¹⁶. It is interesting to note that in this parasite the irradiated larvae appear to penetrate to the tissues below the mucous membrane of the gut and remain there. It is possible that in this position inactivated larvae spend a much longer time in contact with the antibody-forming tissues and hence provoke a stronger defensive reaction than normal larvae. The resistance so produced may be greater than what can be achieved under natural conditions.

In the study of mechanisms of resistance to helminth infection a huge field still remains unexplored which is of immense potential value to the stock rearer and which probably has many applications to the human populations of the undeveloped countries.

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THE APPLICATION OF MODERN GENETIC PRINCIPLES TO LIVESTOCK IMPROVEMENT

The application of genetics to practical livestock improvement rests on three main developments: (i) the discovery of the mechanism of heredity in animals from experiments on major characters such as coat colour, horns and so on; (ii) the proof that the inheritance of continuous variation in characters such as body size or milk yield (that is characters showing a continuous range of expressions between wide limits), is just the same as has been worked out with major genes except that now it is almost impossible to pin-point the effect of individual genes; (iii) the realisation that the manipulation of continuous variation produced by many genes and the simultaneous action of non-genetic forces is essentially a statistical problem and the development of an adequate theoretical framework to integrate the various phenomena observed.

Present day research itself can be roughly divided into four closely related parts, all of which are amongst the Council's activities. They are: (i) the further extension of theory, in the main, perhaps, in the direction of the inclusion of the forces of natural selection^{1,2}; (ii) the experimental verification, on laboratory animals, of existing theory and the provision of evidence on the basis of which theory can be extended^{3,4}; (iii) the analysis, necessarily on a limited scale, of breeding experiments with farm animals carried out under detailed control on the Council's own farms^{5,6}; and (iv) operational research into the livestock industry with the object of discovering the best methods of application of modern genetic ideas in the field⁷.

IMPROVEMENT IN THE LABORATORY

Perhaps the best way to illustrate the problems is to consider how the geneticist in the laboratory would set about changing a population for two different sorts of character and how this is related to the improvement of livestock breeds.

First of all, we can make a few generalities about selection programmes. These can be looked at logically only by considering the whole population of animals which is to be improved. In the laboratory, we would then be concerned to change the mean performance in a population without introducing any new genes from outside. The change would be brought about by allowing only those animals to breed which we thought likely to produce superior progeny. The information on which we make this decision may be the performance of the animal itself, or of its relatives; and the efficiency of such information in predicting the probable performance of the animal's progeny lies at the root of modern quantitative genetic theory. Selection is then *choice* based on *information*; and as it implies some restriction on the number of animals that are allowed to breed, it may lead to the mating of relatives or *inbreeding*. The interplay of these three factors is crucial in determining the best breeding programme. This will then depend further on the character that we are concerned to change and we shall deal with two characters at the extremes of the range.

Let us take as our experimental animal the fruit fly *Drosophila*, in which the generation interval is ten days and in which the offspring produced by each female is in the hundreds. As the character we wish to change, we will take first the number of bristles on certain parts of the abdomen, first studied in detail by Mather and his colleagues⁸. In most wild populations, the flies are very variable; the number of bristles on the female ranges perhaps from thirty to fifty with a mean of forty. Three aspects of this character are important: it can be measured in both sexes; we find that the performance of a sire is a fairly good guide to his breeding merit (i.e. the average performance of his progeny); and the mean count does not alter on close breeding.

In such a case, we should follow a programme of individual or mass selection. In each generation, we would select as parents the extreme members of the population, all of whom had been under the same treatment as far as we could manage it. Our intensity of selection would then be determined only by the necessary number of parents to replace the population. From theory we can predict the probable rate of response under such a selection system and in fact we have found that the prediction gives a fairly good guide to the rate of improvement in the early generations³. One aspect of the problem that we are not as yet very clear about is how to get farthest before we run out of usable genetic variation. It seems probable that we should choose some intermediate intensity of selection (perhaps the best half of the animals measured) in order to get the maximum total progress. In the end when progress had ceased we should expect, on the basis of our experience in laboratory experiments⁹, that there would still be some hereditary variation in the population but that we could not use it to improve the population as a whole. Here we are in a situation very similar to that which we find in a character which is associated with the reproductive fitness of the individual and which has, therefore, been the object of natural selection for many generations.

In *Drosophila*, egg production is a good example of a character of this kind. In designing a selection programme for egg production we have to remember that it can be measured only in females; that the number of eggs laid by a female is not a good guide to the number that will be laid by her daughters; and that egg production is much depressed by close breeding and, consequently, by too great a reduction in the number of parents in each generation.

These factors together present a rather difficult problem. We cannot select at all between males, and any selection we apply to females on their own performance will not be very efficient. We may try to improve the situation by evaluating an animal's genes by looking as well at those animals which have some genes in common, i.e. its relatives, either sisters or progeny. We are then led into a programme of progeny testing or of family selection. The main distinction between these two is that in the former we breed again from the animals which have superior offspring and in the latter we breed from the offspring themselves straight away. To have sufficient members of a family or progeny group for its proper evaluation we have from the very beginning to restrict the number of parents used, and any selection we apply will still further reduce this number. We are in the frustrating situation that those characters for which we will be inclined to suggest a programme of progeny testing or family selection are precisely those which will be most affected by the inbreeding degeneration that will ensue. It follows that such a programme demands for efficient use a fairly large population. This is also necessary because of the difficulty of getting, at the same time, a choice between families and adequate information to judge the merit of each. The general problem of the correct balance between choice and accuracy has been considered both theoretically and in the framework of a progeny testing scheme for dairy cattle at an A.I. centre^{10,11}.

The simplest type of programme in *Drosophila* would then involve the measurement of egg production of members of a number (say twenty) of half-sib families and the selection of males and females from, perhaps, the best four families to produce a similar structure in the next generation. Eventually we would reach a condition in which the gain by each generation from selection was exactly cancelled out by the loss due to inbreeding. It would, however, be possible to produce an even higher level of egg production by crossing two such selected lines to recover from the inbreeding degeneration. We would be even better off if we had several selected lines available so that we could make a lot

of crosses to see which was the best. We then have to remake the cross each generation.

In characters which show considerable improvement on crossing strains or lines, there is still very considerable argument as to how to proceed so as to get the best cross. We have three choices:

- (i) to form distinct strains at random by close inbreeding and then to test all possible crosses between surviving strains;
- (ii) to form distinct strains by selection and mild inbreeding and to test all crosses between such strains;
- (iii) to take strains producing a good cross in (ii) and to try to improve the cross by progeny-testing on the basis of the cross progeny performance either in both lines (reciprocal recurrent selection) or in one only (recurrent selection to a tester).

We need much more experimental evidence on these points.

There is some evidence from poultry that the constituent lines or strains making up the best crosses derive from material which has itself been intensely selected in the pure state. In theory the more rational methods of deliberately selecting for crossing ability as in reciprocal recurrent selection are most appealing but in the only experiments set up in *Drosophila* to test this the best cross was in fact produced by two lines inbred strongly without any selection¹².

This paper has deliberately concentrated on two extreme types of character, firstly, one of little relevance to the ability of the animal to reproduce and secondly, one closely connected with reproductive ability. In between these two, we have a continuous gradation of behaviour in different characters and the sort of programme we might choose will alter accordingly.

IMPROVEMENT OF FARM ANIMALS

How is all this work in the laboratory relevant to practical problems of livestock improvement? What we primarily want to improve is the economy of production or, simply, the "economic value" of the animal. But the place of "economic value" in the spectrum of characters depends on the particular case we are dealing with. All animals have to be born and to survive to perform their economic function, so that we may expect economic value always to be depressed by close breeding. In meat-producing poultry and in pigs, in which the cost of production of the young animal at birth is a small part of the total cost and in which the "economic value" of the live animal (growth rate and efficient food conversion) is not closely connected with reproductive ability, we approach a character like bristles in *Drosophila*. In egg-producing poultry, on the other hand, in which laying house mortality is of great importance and in which egg production itself is at the "difficult" end of the scale, we are dealing with the sort of character in which family selection and progeny testing have to be used, with the possible eventual crossing of selected strains.

In fact, we do not usually select on the economic value of the animal since only rarely can we measure this accurately on individuals. We are able, however, to measure various aspects of the production of the animal and, if we have some idea of which particular characteristics make for profitability, we can balance our selection accordingly. We can also take into account the extent to which performance is an indicator of breeding value for the separate characters. In fact, if the important characteristics of economic merit are similar to our first type of character, we generally find ourselves selecting these and holding our inbreeding sufficiently low for the characteristics affected by inbreeding not to decline seriously.

But the principal difficulties in the way of rational application of genetics to animal improvement lie not in the genetics but in the existing organisation in the

field. For many animals the size both of the breeding unit and of the commercial production unit is far too small. This has several consequences. The small size of the commercial unit means that the commercial producer finds it very difficult to assess the economic merit of the stock that he has bought. This in turn implies that the pressure on the breeder to produce stock of economic merit is not great and he therefore turns to the characters in an animal that he can easily evaluate but which may not be of great value to the commercial producer. The small size of the breeding unit means that it is extremely difficult to run a progeny testing or family selection programme with only a small input of animals on which test information can be gained because it is impossible at the same time to test accurately and have a reasonable level of choice in order to do selection. Any selection that is then done will lead to a high rate of inbreeding within the herd. It is this fear of inbreeding which has led to the practice of buying males into most herds and flocks, so that a very high proportion of the animals in any herd have a sire born in another herd. This interchange of genes between breeding units means that most breeding herds will be similar to each other in genetic merit^{13,14}. We thus have a situation in which few of the breeding units have any long term genetic individuality and in which any selection pressure in these units may well be being exercised in the wrong direction.

If the individual herd is difficult to organize as a breeding unit, to what extent can we consider the breed as a whole as the effective unit? This does happen to some extent at the moment but the fundamental difficulty lies in the effective interchange of information between the different herds which make up the breed. The differences in management level between herds are of such magnitude that the information given by the progeny average of a dairy sire for milk yield relates primarily to the level of management of the herd rather than to the breeding merit of the sire.

The fact therefore has to be faced that the application of genetical ideas to livestock improvement requires that the closed breeding units be much larger than are usual in the bigger kinds of livestock such as cattle and pigs. Furthermore, in these animals the practical demonstration that the geneticists' suggestions are correct demands a considerable expenditure of time and effort, different in scale from that required to test a new cereal variety, herbicide or piece of agricultural machinery. Some of the basic concepts of the modern approach to the inheritance of quantitative variation are also exceedingly hard for the layman to grasp. In these circumstances, it is hardly surprising that, up to the last decade, the impact of genetics on livestock improvement had been slight indeed.

PRESENT AND FUTURE PATTERNS

Perhaps it would be best to close by fitting into this framework the present and probable future pattern in some different types of animals. In egg-laying hens in the United States we have seen the greatest development along what the geneticist would consider to be rational lines. One of the main causes of this has been the "random sample test" by means of which samples of the commercial stock sold by different breeding firms are compared for profitability under standard conditions. The use of this information by the egg producer has provided the economic incentive for the breeder to concentrate his efforts on breeding for profitability. All the signs are that the major part of the business will concentrate in the hands of about five major breeders, all employing geneticists and with effective population sizes running into tens of thousands. There are available in the United States many strains of birds which have been selected intensively as closed flocks for many years. In no case is such a pure strain being sold commercially. The successful commercial stocks are either crosses between such strains or between inbred lines derived from these strains.

Considerable effort is now being put into the improvement of these crosses. It is probable that in Great Britain a similar pattern will develop.

On the other hand, in the application of modern methods to dairy cattle improvement, we are perhaps further ahead on this side of the Atlantic. This has been mainly due to the extensive use of artificial insemination and to the high level of recording. It may be possible to take advantage of the size of the unit and to operate a closed breeding policy based on progeny testing at a single A.I. station. With the support of the Council, this is now being attempted on a pilot scale with Friesians at the Cambridge centre. On a national scale, the existence of accurate progeny tests for yield on a large number of bulls, based on daughters in many herds and evaluated on contemporary comparisons¹⁵, will provide valuable information by means of which the breed as a whole can be improved. The situation has, too, been radically changed by the appearance at auctions of the A.I. authorities as bull buyers concerned primarily with economic points and well provided with information to assess the value of bulls that they have bought in the past and may buy in the future.

Already a high proportion of the young bulls for use in A.I. are being bred by the best tested sires in A.I. But the movement has gone further in Denmark. There, more than three-quarters of the bulls now in A.I. have been sired by A.I. bulls which have been tested in the special progeny testing stations. Although too great a reliance on the station figures may be criticised¹⁶, they have certainly had a tremendous impact on cattle breeding in Denmark. The function of the best individual breeders is then to concentrate the blood of the best sires in A.I.

Lastly, in pigs we are in Great Britain at a critical stage. We have built a series of progeny testing stations—an attempt to provide comparative information on a breed scale. The question now of importance is how this information is to be used. Are we to follow Denmark, where such stations have led to the gradual improvement of the Danish Landrace as a bacon pig¹⁷, or perhaps Canada, where the testing stations had little or no effect on the major breeds¹⁸. However, we must not forget that many of the economic characters in a bacon pig, in particular rate of gain and back fat thickness, can be observed on the live pig. The setting up of boar performance testing in the U.S. for the measurement of these characters on the live boar, and its enthusiastic acceptance by the breeders in some states, are an indication of the direction in which things are moving.

In summary, it is felt that our present knowledge of genetics and of its probable application to animal improvement is such that in several of the animals our main problem is to apply our knowledge and see if it works. There are, of course, several aspects about which we are still uncertain—in particular, how to proceed to reach the furthest limit of progress and how best to select for crossing ability. In view of the part which characters affected by inbreeding depression play in economic merit in all our animals, it appears likely that in all cases we must be looking forward to the final product being a cross of some kind. In some cases this point is perhaps far ahead in that we have plenty of variation available for selection in the pure state. But the severe selection programme and consequent high rate of inbreeding that some strains are now being subjected to would suggest that we should not leave this possibility too much out of our minds.

The applied geneticist is in a special position amongst agricultural scientists in that he demands a large number of animals not only for the analysis of the basic situation but also for the full play of his ideas in bringing about improvement. Up to the present such conditions have not existed but the success of the geneticist in applying his knowledge in the poultry industry in the United States is encouraging for the future.

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FERTILIZER PLACEMENT INVESTIGATIONS

If manures or fertilizers are to be of any value to crops they must be applied to the soil in such a way that they can be reached by roots. Fertilizers broadcast over the surface may be mixed with soil by cultivations, or if they are soluble they will be washed into the top layer of soil by rain. A contrasted method is to concentrate fertilizer in pockets or in continuous bands close to lines of seed, or beside the rows of established crops; this practice is generally given the name "Fertilizer Placement". It is not a new idea—English writers of the seventeenth century described drills which were intended to sow bands of both manure and seed but it is doubtful if many of these machines were ever constructed. When fertilizers became more widely used during the last century machinery-makers in England developed distributors to spread them uniformly over the land. For more than 80 years after chemical fertilizers were introduced the only placement machines in use in this country were rather primitive root-crop drills which were common in the Fenland and in a few other restricted areas. In other countries, such as America and Australia, large areas of land had to be sown as quickly as possible and "combine-drills" were developed for cereals to sow seed and

fertilizers together. In England a few farmers achieved the same effect by sowing mixtures of seed and fertilizer from ordinary drills but placement methods were little used here until combine-drills were introduced just before the war.

EXPERIMENTS ON CEREALS

Combined seed-and-fertilizer grain drills were imported from America and Australia during the 1930's by farmers who were developing mechanised methods of cereal growing in Southern and Eastern England; their main object was to combine the two operations of seed-sowing and fertilizing which until then had been carried out separately. During the war large areas of permanent pasture in poor condition were ploughed up for cereal growing. Most of the soils used were very deficient in phosphorus and some were deficient in potassium. Practical trials on such land showed that using a combine-drill to apply fertilizers with the seed was a much better way of ensuring a good crop of corn than broadcasting fertilizers separately before sowing. Field experiments were initiated in 1943 to investigate the benefits of combine-drilling. The early work on cereals was carried out under the direction of a Conference on Fertilizer Placement set up by the Agricultural Research Council and with the co-operation of County Technical Development sub-Committees of the Ministry of Agriculture. After the war ended the value of placement methods for other common crops was investigated under the auspices of a Technical Conference of the Council which co-ordinated the work and helped in its planning and execution.

Phosphorus

The first experiments, carried out during the war and reported by Crowther⁷, showed that combine-drilled superphosphate was more effective than broadcast superphosphate for wheat, barley and oats. A small dressing drilled with the seed gave as much grain as twice as much broadcast. These results pointed the way both to economies in the use of superphosphate and to higher yields; they were quickly put into practice during the war period and afterwards.

Potassium

Other war-time experiments, briefly reported by Crowther⁷, were carried out on the calcareous potassium-deficient soils which resulted from ploughing the Chalk Downland of Southern England. A small quantity of potassium chloride drilled with barley seed gave much higher yields than broadcasting twice as much potassium before sowing. In more recent experiments there were similar gains from combine-drilling potassium fertilizers for barley grown on deficient soils in Bedfordshire and Hertfordshire.

Nitrogen

The gains from drilling nitrogen fertilizers for cereals are smaller but in some recent experiments Widdowson & Cooke¹¹ showed that ammonium sulphate drilled with the seed produced over 2 cwt. per acre more barley grain than was given by broadcasting the same fertilizer dressing on the seed bed before sowing. Top-dressings of "Nitro-Chalk" broadcast in the middle of May also gave lower yields of barley than an equivalent amount of combine-drilled ammonium sulphate and they also increased the risks from lodging. Although spring-sown wheat gives smaller responses to nitrogen than barley, combine-drilling ammonium sulphate with wheat has given better yields than broadcasting this fertilizer.

EXPERIMENTS ON POTATOES

The traditional English way of planting potatoes is to put up the land in ridges, plant seed by hand in the furrows between, and then to split the ridges to cover the seed; a compound* fertilizer is applied at some stage before planting

* Fertilizers containing only one plant nutrient are usually called "straight" fertilizers; "compound" fertilizers contain two or three of the nutrients: nitrogen, phosphorus, and potassium, "complete" fertilizers contain all three nutrients.

the seed. Early experiments carried out by Cooke¹ compared different ways of applying a complete potato fertilizer for crops planted in this way. Fertilizer dressings placed at the side of the seed by a special machine gave the same yields as the same amount of fertilizer broadcast over the furrows immediately before planting. Fertilizer broadcast on the flat land before drawing out the furrows for planting was mixed with the soil in the ridge and was less effective. On average 15 cwt. per acre of fertilizer broadcast in this way was needed to give the same yields as only 10 cwt. per acre broadcast over the furrows just before planting. These experiments showed that fertilizer efficiency can often be improved merely by using ordinary broadcasting equipment in a special way. When fertilizer is broadcast over furrows just before planting potatoes, splitting the ridges after planting concentrates the dressing over and around the seed and there is nothing to be gained from special placement methods.

Since 1947, when these experiments were concluded, potato-planting machines have become very common and now more than half of the acreage is planted mechanically. When a machine is used to plant potatoes and form the ridges in one operation there is no opportunity to concentrate broadcast fertilizer near the seed. However, if the planter is fitted with an attachment to place fertilizer in a band 2 inches to the side of the seed potatoes and slightly below them the dressing is fully effective. Cooke *et al*⁵ showed that 15 cwt. per acre of fertilizer broadcast before planting was needed to give about the same yields as only 10 cwt. per acre of placed fertilizer. On most ordinary soils in England potatoes are likely to give similar results from placement and the extra cost of buying a proper fertilizer attachment for a planter may be written off after planting only a few acres. Many mechanical planters on the market place fertilizer in contact with the seed. The experiments showed that this practice is dangerous when heavy fertilizer dressings are used in a dry spring.

EXPERIMENTS ON ROW CROPS

Arable farmers who were impressed with the success of combine-drills for cereals tried these machines for sowing fertilizer with the seed of crops grown in more widely-spaced rows. Often germination was damaged and yields were reduced when normal dressings of complete fertilizers were drilled with the seed of crops like sugar beet and peas. An investigation was therefore planned to find the best ways of applying fertilizers for crops normally grown in rows spaced 14 inches or more apart. As there were no commercially-made drills suitable for applying fertilizer in different ways near to the seed, the Council asked the National Institute of Agricultural Engineering to construct special machines for this purpose. The Institute had already built a fertilizer drill for the first series of potato experiments described above and from 1946 onwards they built several machines which were used to lay down field experiments carried out by the Macaulay Institute for Soil Research and by Rothamsted Experimental Station. The first models of these drills were available in 1947 and were used in both Scotland and England to develop and test safe methods of placing fertilizer in bands close to the seed. The extent of injury to germination depended on the nature and amount of fertilizer used, the texture and moistness of the soil at sowing, and the weather that followed. Dressings of soluble nitrogen and potassium fertilizers placed either with, or directly below the seed, were dangerous but superphosphate used in this way rarely caused any harm. Comparisons between a single sideband placed either 1 inch or 3 inches to the side of the seed, and approximately 3 inches below the soil surface, showed that a distance of 1 inch was too close to the seed for safety and that 3 inches was too far away to be effective. A standard placement position was therefore adopted for row crops, fertilizer being placed in a band 2 inches to the side of the seed and 1 to 2 inches deeper. This method, which was quite safe for all crops, was compared with the normal way of broadcasting a fertilizer dressing and working

it into the seedbed before sowing. The results of the work have been described by Cooke² and by Cooke and Widdowson⁴; they are summarised in the following paragraphs.

Peas and beans

If phosphorus and potassium fertilizers are broadcast for peas and beans they are not likely to give an economic return except on soils which are deficient in these nutrients; experiments were therefore begun in 1947 to see if better returns could be obtained by placing fertilizer in bands beside the seed. For threshed peas, for peas picked green, and for both winter and spring beans placing a compound fertilizer beside the seed gave higher yields than broadcasting twice as much. The gains from placement as compared with broadcasting averaged about 2 cwt. per acre of dried peas, about 8 cwt. per acre of peas picked green, and more than 1 cwt. per acre of field beans. For both beans and peas the extra yields given by broadcasting fertilizer were not sufficient to repay the cost of the dressing but the extra yields from placement were profitable and were sufficient to justify the cost of the special drill needed to put the method into practice.

Horticultural crops

Placing a complete fertilizer in a band to the side of the seed gave higher yields than broadcasting fertilizer in experiments on drilled cabbage, lettuce, onions, maize, spinach, broad beans, french beans and runner beans. For many of these crops a single dose of complete fertilizer placed beside the seed gave higher yields than twice as much broadcast fertilizer⁶. Lettuce, cabbage, runner beans, and broad beans grown with placed fertilizer were ready to market earlier than those with broadcast fertilizer. These advantages of quicker development and higher yields through placement may be very profitable to growers as early vegetables often command high prices.

Swedes and turnips

In English experiments on swedes grown on unridged land placing a complete fertilizer mixture beside the seed gave higher yields than broadcasting. Other experiments on swedes have been carried out by Reith⁸ in Scotland where most roots are grown on ridged land and dressings broadcast on the seedbed are easily concentrated in setting up the ridges. With this Scottish method of planting placing a complete fertilizer in a band at the side of the seed gave the same yields as broadcasting the dressing before sowing.

Sugar beet, mangolds and kale

Fertilizer dressings placed in bands beside the seed usually make sugar beet, mangolds and kale grow much more quickly in spring than broadcast dressings, but in the experiments, as the season advanced, these differences between broadcasting and placing became smaller and had vanished at harvest. Very similar yields were given by placed and by broadcast fertilizer³.

EXPERIMENTS ON HERBAGE CROPS

Temporary grassland

A high concentration of phosphate near the seed of grasses and clovers is essential for satisfactory establishment of a ley, particularly on deficient soils. Stewart & Reith¹⁰ showed that in Scotland drilling phosphate fertilizers with the seeds mixture promoted better establishment of temporary grassland than broadcasting phosphate before sowing.

Lucerne

Placing fertilizer dressings at the side of the seed has no advantage over broadcasting for lucerne but a small quantity of superphosphate drilled directly

beneath the seed is much more effective. In experiments this "starter-dose" gave better growth and higher yields than broadcasting much heavier dressings of superphosphate before sowing.

Established Crops

Fertilizers are always broadcast over established herbage crops. As dressings of phosphorus and potassium fertilizers applied in this way may remain on the surface of the soil during dry periods and be of little value, the possibility of applying fertilizer in bands below the surface of the sward has been examined. Dressings of phosphorus and potassium fertilizers drilled in bands 3 inches below the surface of lucerne and sainfoin stands and of permanent grass gave lower yields of hay than dressings of the same fertilizers broadcast on the surface. It seems that the advantages of an equal supply of nutrients to all the plants in an established sward outweigh any disadvantage due to confining the dressings to the surface.

PLOUGHING IN FERTILIZERS

Russell⁹ found that by ploughing in phosphorus and potassium fertilizers to a depth of 8 to 10 inches, two-thirds of a ton more beet was obtained per acre than when they were harrowed into the seedbed. Ploughing down the fertilizers 12 to 16 inches deep on sands and sandy-loams also gave higher yields than broadcasting them on the seedbed but with this depth of ploughing on heavy soils seedbed applications were superior. There is not sufficient evidence to justify a general recommendation that farmers should plough in phosphorus and potassium fertilizers for all crops but there are advantages from incorporating these nutrients deeply in the soil for deep-rooting crops such as sugar beet and lucerne.

THE PRACTICAL APPLICATION OF FERTILIZER PLACEMENT RESEARCH

British farmers have made good progress in applying the results of the placement research carried out in this country.

Cereals

Combine-drilling of seed and fertilizer, the simplest form of placement, is now very widely used for cereals. The growth of the practice is illustrated by the changes in the numbers of ordinary grain drills and of combine-drills in use on farms in England and Wales during the last sixteen years. In 1942 84,000 ordinary drills were being used and there were only 7,000 combine drills. In 1956 the number of ordinary drills used was the same as in 1942 but the number of combine-drills had increased six times to 42,000. These machines now account for one-third of all the grain drills owned by farmers. These figures take no account of the amount of work which different types of drill carry out. On many farms most cereals are sown by combine-drill, the older type of ordinary drill being retained for occasional use when no fertilizer need be applied.

Potatoes

Fertilizers applied to potatoes planted by machines are only used efficiently if they are placed in a band in a safe position at the side of the seed. About half of all the potato planters marketed in this country have a fertilizer attachment mounted on the planter. Of the planters sold with an attachment, many are built to place part or all of the fertilizer dressing in contact with the seed potato in the planting shoe, a procedure which may lead to damage to sprouting when seedbeds are dry. Other machines allow the fertilizer to fall ahead of the planting shoe so that after planting the dressing is concentrated in the upper part of the ridge where it cannot be used efficiently by the crop. At present only a few planters are fitted to place a fertilizer band in a satisfactory position at the

side of the seed. No precise estimate can be made of the proportion of the machine-planted potato acreage which receives fertilizer from an attachment on the planter but it probably amounts to one-half. Correct sideband placement is used on only a small fraction of this acreage.

Row crops

A number of satisfactory row-crop placement drills are now marketed and several makers of combine-drills offer additional equipment to convert their machines so that fertilizer can be placed in sidebands for crops grown in widely-spaced rows. Sideband placement drills are now widely used by growers of beans and peas, particularly where crops are grown on contract for canning or freezing. Some farmers use placement drills for crops such as sugar beet which give similar yields from placed and broadcast fertilizer; they use the method because placement eliminates separate broadcasting of fertilizers before drilling, so saving labour and tractor costs, and avoids the separate passage of tractor and fertilizer drill over the seedbed which may consolidate the soil too much.

Correct placement, whether achieved by special machines or by a particular way of broadcasting, is essential if the best returns are to be obtained from fertilizer dressings. In general, the benefits from placement are likely to be greatest on soils that are deficient in available plant nutrients; the technique often allows crop production on poor soils to be brought up to a high level economically and quickly. On the richer soils placement is a suitable way of applying the small dressings needed as insurance against unsuspected soil deficiencies, attacks by pests and diseases, or unfavourable growing conditions.

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FUTURE DEVELOPMENTS IN CHEMICAL WEED CONTROL

Chemicals have been used for the control of weeds since the beginning of the century, but it was not until the discovery in 1941⁸ that plant growth regulating substances, such as MCPA (4-chloro-2-methyl-phenoxy acetic acid) and 2, 4-D (2, 4-dichlorophenoxy acetic acid), could control weeds growing in cereal crops that agriculturists began to take such methods of weed control seriously. Before the last war the more progressive farmers were spraying their cereals with copper

sulphate and sulphuric acid and during the early years of the war DNOC (2-methyl-4, 6 nitrophenol) was introduced, but these chemicals were unpleasant to handle, poisonous and played little part in crop production. After the war, when MCPA and 2, 4-D became generally available and methods for the use of these non-poisonous water soluble compounds had been worked out by an Agricultural Research Council team led by Blackman¹, progress was rapid. Developments during the last twelve years in the use of chemical weedkillers—herbicides—for the selective control of weeds in agricultural crops and the non-selective control of unwanted vegetation on non-agricultural land and in water have already had a profound effect on both the pattern of farming and the management of uncropped land.

THE PRESENT POSITION

It is estimated that approximately 2½ million acres of cereals in the U.K. are sprayed annually with herbicides. In addition a considerable acreage of grassland and forage crops, as well as other arable crops and vegetables, are treated. Estimates of the extent of these uses of herbicides are lacking, but the increase in the number of ground crop sprayers on farms and small holdings in England and Wales from about 9,000 to 33,000 between 1952 and 1956 gives an indication of the rapid expansion that has taken place in these new techniques. Progress in the development of chemical methods for the control of undesirable vegetation in other situations has not been so spectacular in this country, but those responsible for the maintenance of railways, roads and industrial sites are already making use of some of the advantages that chemicals possess, and, with the introduction of new chemicals that are not toxic to fish, the Drainage Authorities and River Boards are experimenting with chemical methods for the control of aquatic weeds².

The main emphasis in the post-war development of herbicides in the U.K. has naturally been on the selective control of agricultural weeds and, in particular, weeds of cereal crops. Today it is possible to control nearly all the common dicotyledonous weeds that occur in cereal crops and most that are troublesome in undersown cereals. Nine different chemicals are available. In addition to MCPA, 2, 4-D and sulphuric acid the farmer now has the choice of six other chemicals:—

MCPB	...	4-(4-chloro-2-methylphenoxy) butyric acid
2, 4-DB	...	4-(2, 4-dichlorophenoxy) butyric acid
mecoprop	...	(4-chloro-2 methyl phenoxy) propionic acid
C.P. 1815	...	a mixture of MCPA and 2, 3, 6 trichlorobenzoic acid
SMA	...	sodium monochloroacetate
dinoseb	...	2-(1-methyl-n-propyl)4-,6-dinitrophenol

Each of these herbicides has its own particular selective action, and the question is not "Can the weeds be killed with herbicides?", but "Which herbicides should be used?". The decision which to apply in any given situation depends on a knowledge of the relative susceptibility of the important weeds to each chemical, the tolerance of the different cereals and the comparative costs of the doses required. Such information has been brought together in The Weed Control Handbook¹⁰, but, even so, reference tables of the type prepared by Fryer⁴ are necessary to enable the layman to choose the most effective treatment.

Wild oats (*Avena fatua* and *A. ludoviciana*), black grass (*Alopecurus myosuroides*) and certain perennials such as couch grass (*Agropyron repens*), are now the only important weeds of cereals that cannot be controlled chemically in the crop. Where these weeds are not a problem, the cereal has become the cleaning

crop in the rotation and there is no longer any need to include a row-crop in order to keep the land weed free.

Less progress has been made in the control of weeds in other arable crops. Peas can be sprayed with dinoseb and MCPB; lucerne with 2, 4-DB and dalapon (2, 2-dichloropropionic acid); carrots with mineral oils; potatoes with DNOC before the crop emerges and MCPA afterwards; kale with sulphuric acid, SMA and potassium cyanate; beet with sodium nitrate; but not all of these treatments are selective enough to be generally accepted.

Many of the perennial weeds of grassland, particularly buttercups (*Ranunculus* spp.), thistles (*Cirsium* spp.), rushes (*Juncus* spp.), docks (*Rumex* spp.), dandelion (*Taraxacum officinale*), and nettle (*Urtica dioica*) can be controlled and the application of herbicides is becoming an accepted part of the management of permanent pastures, as well as in the establishment and maintenance of short and long term leys. Unproductive grasses are still the most important weeds of grassland and as yet there is no herbicide that is recommended for their control.

For some vegetable crops, such as peas and carrots, there are efficient herbicides that can be applied as foliar sprays and these are widely used, but for all other vegetables the herbicides so far developed are less satisfactory and the grower has to resort to rapidly acting contact herbicides, such as pentachlorophenol or cresylic acid formulations, that kill the weeds before the crop emerges above ground—Roberts⁷. In fruit growing too, few satisfactory herbicides are available. Chemical weed control in horticultural crops is in fact only just beginning and has reached a stage comparable to that which existed for cereals at the time of the discovery of MCPA and 2, 4-D.

THE EXISTING PATTERN OF DEVELOPMENT

The amount of time and money devoted to the control of unwanted vegetation is immense. It has been estimated that agricultural weeds alone cost this country £50,000,000 annually⁵. There is, therefore, much to be gained, both by the manufacturer of herbicides and by the user of these materials, in the development of new and more efficient chemicals, and it is not really surprising that the present position with regard to the use of herbicides in this country has been reached largely as a result of the efforts of the agricultural chemical industry. The State was able to lead the way during the war years, but subsequently practically all the new herbicides have been discovered and developed by commercial firms. Many thousands of chemicals are tested annually by industry, in laboratories and glasshouses, in order to determine their phytotoxic properties. The few that are selected and fulfil the necessary requirements of effectiveness, cheapness, convenience in handling and, last but not least, patentability are further assessed under field conditions. In this country, much of the preliminary testing in the field, done with the object of drawing up recommendations for the user, has been undertaken by agronomists attached to the experimental stations of the larger commercial firms. The State, however, is ultimately responsible for advising the grower on the suitability of these new chemicals and has therefore set up its own research organisation in order to carry out independent assessments of important new herbicides and to issue its own recommendations. The A.R.C. Unit of Experimental Agronomy at Oxford has been concerned with these problems. By working in collaboration with industry, the National Agricultural Advisory Service and the research institutes it has been able to make a start on the precise evaluation of crop safety limits and to obtain accurate information on the susceptibility of most of the important weed species to some of the new herbicides. In addition, with the co-operation of all the interested parties, the staff of the Unit edits the Weed Control Handbook¹⁰ published annually by the Weed Control Council, which serves as a guide to the

research worker, the N.A.A.S. Advisory Officer and the grower, as well as to the Crop Protection Products Approval Scheme administered by the Ministry of Agriculture, Fisheries and Food and by the Department of Agriculture for Scotland.

THE FUTURE

This pattern of development, which is essentially a routine screening of all potential new chemicals followed by an *ad hoc* field evaluation, has been strikingly successful. There seems no reason to doubt that it will continue to bring to light equally good herbicides for an increasing range of weeds of arable crops and grassland. Similarly, herbicides will be discovered for the selective control of weeds in vegetables, fruits, flowers, shrubs and trees. The rising cost and increasing shortage of manual labour will eventually make the use of chemical weedkillers essential in all crops that cannot be weeded mechanically. Herbicides are only just beginning to be employed in many horticultural crops and it is unlikely that their adoption in the future will be as rapid as it has been in cereal crops. Despite the higher value per acre of many horticultural crops, the great range of the species and varieties, as well as the added importance of quality, will necessitate more extensive and careful field evaluation.

It is relatively easy to find a chemical which when tested in the glasshouse is more toxic to one species of plant than another. The difficulty is to find chemicals that are fool-proof enough for general acceptance and that are required in sufficient quantities to warrant manufacture. In order to be fool-proof a herbicide has to be highly selective in its effects on crops and weeds. Unfortunately the more selective a herbicide the more limited is its application. This inverse relationship between safety and demand means that industry is not always interested in manufacturing the most efficient herbicide. For instance, 2, 4, 5-TB (4-(2, 4, 5-trichlorophenoxy) butyric acid) is recommended for the control of bindweed (*Convolvulus arvensis* and *Calystegia sepium*) in blackcurrants⁶, but as it does not have any other outlet it is not manufactured and the grower has to employ less efficient methods of control.

Obviously it would never be practical to have a herbicide for every different combination of weed and crop, but the balance between efficiency and safety on the one hand and the economics of manufacture on the other may well swing towards increasing specialization. It seems possible, therefore, that in the future the initiative for research and development, as well as for advising and assisting the grower, will gradually pass from industry to the State.

As the list of herbicides increases and the particular requirements become more specific, it will be necessary gradually to replace the routine methods of screening and evaluation by others based on an understanding of the physiology of phytotoxicity and the principles underlying selective phytotoxic action. Gradually the science on which the technology is based will take shape. Additional information will be forthcoming on the mechanisms of the entry of herbicides into plants, their movement and persistence both in plant and soil and the nature of their toxic actions. Such information is necessary for a rational approach to the synthesis of new herbicides, as well as to the understanding of the many plant, soil and climatic factors which, together with formulation and method of application, determine the results obtained in the field. Research of this type has been sponsored by the A.R.C. and constitutes the major part of the research programme of the Unit of Experimental Agronomy.

In this new branch of agriculture, basic research has lagged far behind the technology and so far has been of little help in the practical solution of field problems. Almost all the herbicides that are available to the grower have been discovered by routine screening and testing methods. One exception is the group

of selective herbicides discovered by the A.R.C. Unit of Plant Growth Substances and Systemic Fungicides—Wain⁹. MCPB and 2, 4-DB are members of this group and are the only important herbicides that have been developed from fundamental work carried out in a non-commercial research laboratory.

THE IMPACT OF HERBICIDES ON METHODS OF CROP PRODUCTION

Most herbicides that have been marketed in this country have been intended as treatments that would fit into the normal husbandry of the crop. They are applied by conventional machinery and do not require any adjustment in the accepted methods of growing the crop. This is the type of product that is likely to be produced from the routine testing methods that industry employs for the development of new pesticides. It is, however, misleading to think of herbicides as acting in this limited way and to regard them simply as pesticides. Herbicides, unlike insecticides and fungicides, control pests which otherwise would have to be dealt with by other means. They are always an alternative to cultural methods of weed control and are therefore a part of husbandry rather than a remedial treatment applied when the situation gets out of hand. The art of growing crops is largely a battle with weeds and the ability to keep them in control has generally been considered as the mark of a good husbandman. New methods of control that eliminate the necessity for the traditional methods are already revolutionizing farming systems.

NECESSITY FOR CULTIVATIONS

The advantages of herbicides must be thought of not solely in terms of the weeds they kill, but in the wider context of how they can improve the efficient use of land. Their existence makes it necessary to reconsider the value of many of the old established cultural practices and to decide afresh: (i) the necessity for cultivations in addition to those required for weed control; (ii) the most efficient crops and rotations if cultivations for weed control are no longer needed.

We have not yet reached the stage in British agriculture where cultivations for weed control are no longer required, but we are approaching this situation in modern methods of growing cereals, peas, forage grasses, lucerne and in a few horticultural crops such as asparagus and strawberries.

Chemical weed control in the arable rotation can be accomplished either selectively during the growth of the crop or non-selectively during the autumn and winter months when the ground is fallow. In our climate this latter period offers much promise for the control of perennial weeds such as creeping thistle (*Cirsium arvense*), couch grass (*Agropyron repens* and *Agrostis* spp.) and coltsfoot (*Tussilago farfara*). If weeds could be controlled by such methods then on many of the lighter lands ploughing might not be required.

Cultivations in fruit crops, such as strawberries and blackcurrants, often damage the roots of the crop and in this respect are definitely harmful. Citrus growers in the irrigated areas of California have found that they can keep their soils free from weeds by the application of herbicidal oils and monuron (N(4-chlorophenyl)-N', N'-dimethyl urea). They find, after four years without cultivations of any sort, that yields have increased and the soil structure has not deteriorated. It remains to be determined whether similar chemical methods of weed control can be devised for some of our perennial crops and if they can, what place, if any, cultivations will play in good husbandry.

INFLUENCE ON CROPPING

Efficient herbicides contribute to a freedom of choice in cropping that enables the grower to make the maximum use of his land. In the search for new herbicides, and in the development of the new chemicals when they are found,

much importance will have to be placed on the need for investigating the problems associated with the integration of the herbicides into existing cultural systems and in the evolution of completely new techniques.

The effect of the herbicide may simply be to allow the growing of desirable crops more frequently. Weeds are a very important factor influencing the present systems of crop production and rotation. As our ability to control weeds by chemical means increases, we shall find it necessary to make an appraisal of present methods of husbandry that are largely determined by the need for controlling weeds. More emphasis will be placed on the efficient use of land and machinery and the need for rotational cropping will diminish. We have already seen how herbicides have made it possible to grow successive crops of cereals without the danger of encouraging any serious weed problems. It is likely that it will be possible to grow other arable crops continuously without the need of a break in order to keep weeds under control, provided diseases and pests can be kept in check. During the interim phase before universal chemical weed control has been attained it may also be necessary for farmers, who are faced with difficult weed problems, to consider growing special crops that will allow the limited capabilities of existing herbicides to be utilized.

NEW METHODS OF HUSBANDRY

Herbicides may enable profound changes to take place in the existing methods of husbandry, and many lines of research and development work on possible new agronomic techniques suggest themselves. For instance, the complete mechanisation of the sugar beet crop depends just as much on a weed-free seed bed as on the use of a precision drill and monogerm seed. The most likely method of attaining this freedom from weeds is to incorporate a soil-acting herbicide into the top few inches of the soil at the time of seeding. An experimental machine which combines a precision drill with a spray nozzle and a small rotary cultivator is being made by the National Institute of Agricultural Engineering for trial, in the first place, at the Norfolk Agricultural Station.

A good example of a new technique which is solely due to the use of herbicides is the destruction of grass swards, prior to surface reseeding, by dalapon and amino triazole (3-amino-1, 2, 4-triazole) instead of by the plough³. It appears that there may be a number of situations where this chemical method is preferable to ploughing, for instance, in fields which are too wet, steep or stony to permit the passage of heavy tillage implements. It has also been found that surface reseeding avoids loss of compaction in the seed bed which can be a difficulty after ploughing-in swards and is often an important factor influencing the successful establishment of seeds.

The possibilities of the chemical control of vegetation are immense. The study of the practical applications of chemicals that kill plants is often closely related to the study of those that merely suppress growth, and neither can be sharply separated from chemicals that stimulate growth. The herbicide MCPA, for example, is a plant auxin and can under certain artificial conditions increase "growth". Maleic hydrazide is a chemical that can cause a cessation of growth rather than death. At appropriate doses it is a "herbistat", not a herbicide, and is used, among other things, for depressing the growth of grasses on verges of trunk roads.

Many herbicides when applied in low doses suppress growth. In grassland, where desirable and undesirable species are growing in close association, a chemical need only tip the ecological balance in favour of the desirable species to be of immense practical importance. Just as sulphate of ammonia can be employed to suppress clover in a lawn, so low doses of herbicides can be used to suppress and eventually control weedy grasses in pasture. The two most widespread weeds of British grassland are *Agrostis* spp. and *Festuca rubra*, and if a

chemical could be found that was more toxic to these species than to the other more useful grasses it might have a very important part to play in improving the millions of acres of *Agrostis*-dominated permanent pastures of this country.

Revolutionary progress of this kind can be achieved only as the result of long term investigations of both the basic and the applied aspects of the problems. Industry may be expected to play its part in the search for the new chemicals that will make these new techniques possible and in the basic studies on the mechanisms of action, but much of the agronomic and ecological work in relation to the chemical treatments, as well as the more fundamental studies underlying the whole subject, must be the responsibility of those official organisations that are concerned with agricultural progress in this country.

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- ⁴ FRYER, J. D., 1958. Choosing the Best Herbicides for Cereals. *Agriculture, Lond.* **64**, 585-592.
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- ⁸ SEXTON, W. A., SLADE, R. E. and TEMPLEMAN, W. G., 1941. Brit. Patent 573,929 (Appln. date 7th April, 1941).
- ⁹ WAIN, R. L., 1955. A New Approach to Selective Weed Control. *Ann. appl. Bio.* **42**, 151-157.
- ¹⁰ Weed Control Handbook. Blackwells Scientific Press. 1958, pp. 231.

THE INTRODUCTION OF ELECTRONIC COMPUTERS IN RESEARCH STATISTICS

Owing to the variability of the subject material, biological and agricultural research frequently gives rise to problems of interpretation which are essentially statistical in nature. The development of statistical methods adequate to deal with such problems is comparatively recent, its foundations having been laid by the researches of R. A. Fisher at Rothamsted during the years 1919-1931. Fisher greatly extended the mathematical theory of estimation and tests of significance, particularly small sample theory which is so frequently required in agricultural and biological research. A most important practical contribution by the Rothamsted school to research techniques is that of experimental design. Designs have been developed which are statistically sound and are at the same time capable of giving, with no more experimental effort, a far greater amount of information than had previously been possible. Associated with these new types of design are methods of analysing the result (generically known as the "analysis of variance") which give valid and unequivocal estimates of the experimental errors. Important contributions have also been made to the statistical methodology applicable to genetics and to the sampling of biological and other variable material.

The introduction of these new statistical methods has brought about a revolution in the more quantitative types of agricultural and biological research, in which statistics is now a recognised and widely used tool. This revolution could scarcely have been effected were it not for the widespread introduction, at about the same time, of desk calculating machines. Without such machines the calculations necessary to utilise the new methods would scarcely have been practicable. Equally the day-to-day use of the new methods in the analysis of problems arising in the field and laboratory has resulted in their further development and refinement.

Desk calculating machines have their limitations. While they are very suitable for univariate analysis such as is required for the analysis of variance and similar computations, they are very much less effective for multivariate work. Consequently the practice of multivariate analysis has lagged considerably behind univariate analysis. Indeed it has become increasingly apparent in recent years that the development of many branches of statistics is being held up through lack of adequate computational facilities.

For the analysis of survey data punched card machinery, first developed for census work, has been available. Punched card machinery is, however, primarily designed for sorting, counting and totalling operations, and does not readily lend itself to the more elaborate types of computation that are required for the critical analysis of the research surveys.

The recent introduction of general purpose electronic computers has opened up entirely new possibilities of computation. In order to explore their utilisation in research statistics the Agricultural Research Council arranged with the National Research Development Corporation for an electronic computer to be installed in the Statistics Department of Rothamsted Experimental Station early in 1954. This was a prototype model, the N.R.D.C.—Elliott 401, built by Elliott Brothers under a development contract with the N.R.D.C. It is a moderate-sized and relatively simple machine with a magnetic disc memory of 2944 numbers (“words”), but it has proved sufficiently large and fast for the initial exploratory work.

It is often thought that the main feature of an electronic computer is its speed. This is only part of the story. Equally important is its ability to perform long and complicated trains of operations without the intervention of the human operator; indeed, without this feature speed would be of little value. It can also make decisions, the basis for which depends on some numerical value already reached in the course of a computation or on the value of some parameter supplied with the data. Thus, for example, a computer can be instructed to carry out alternative operations which depend on contingencies indicated by the data and can terminate a process of successive approximation when the solution has attained the required accuracy.

The operations which are to be carried out are governed by what are termed “orders” which are held in the memory (“store”) of the machine in the form of numbers. The whole collection of orders controlling a given type of computation is known as a “programme”. Programmes can be so written that they have sufficient generality to handle a range of problems of a given type, but to effect this substantially more orders are often required. The store of the machine is used both for the orders of the programme and for data, intermediate values and results. Consequently a large store is essential for most types of statistical work.

To give an idea of the speed at which electronic computers operate it may be mentioned that in the Rothamsted machine, which operates with numbers of 32 binary digits (equivalent to about $9\frac{1}{2}$ decimal digits) addition or subtraction is effected in 0.1 msec. (0.0001 sec.) and multiplication in 3 msec. The overall speed of the machine for particular computations depends not only on the speed

of individual arithmetical operations but also on a number of other factors which need not be discussed here. Suffice it to say that compared with any other method of computation electronic computers are exceedingly fast.

The fact that the operations are governed by orders held in the machine as numbers makes it very easy to change over from one type of computation to another. All that is necessary is to feed in the appropriate programme. This is normally recorded either on punched teleprinter tape or on punched cards. There is then complete assurance, provided the programme is correct and the machine is operating correctly, that it is set up correctly for the required job, which can be undertaken immediately the data, similarly recorded on punched tape or punched cards, are fed in. The results are likewise recorded mechanically on punched tape or punched cards, from which a typed record can be produced.

These features make it possible to carry out the whole of a complicated numerical analysis at very high speed without the intervention of a human operator. It was early apparent, therefore, that electronic machines were likely to be of very great value in the more standard types of statistical analysis and would make possible many types of analysis which were not previously practicable. Indeed, they may be expected to bring about a revolution in method quite as great as that which resulted from the general adoption of desk calculating machines.

Since its installation the Rothamsted computer has been used for a wide variety of statistical computations, a few of which will be briefly described so as to indicate the ways in which the uses of the machine are being developed and the possibilities for the future.

Before the acquisition of the electronic computer the main load of routine computing work in the Department was the analysis of the results of agricultural field experiments, both on crops and animals, and also the results of research surveys on agricultural problems. It was natural, therefore, to investigate the potentialities of the computer in these directions.

As has been pointed out above, the analysis of the simpler types of replicated experiment can be carried out quite effectively on desk machines, and at first it seemed doubtful whether electronic computers would in fact offer any great advantages over desk machines. It was soon found, however, that once the necessary programmes had been written, the analysis on the computer of even such simple designs as randomized blocks and Latin squares resulted in substantial gains in speed and economy of labour, and also in greater accuracy; the advantages of the computer over desk machines naturally increase with the complexity of the design.

One important lesson that was early learned was that it paid to do the whole of the analysis on the computer, including the preliminary calculations of such quantities as, e.g., yields of sugar from weights of roots and sugar percentages, and to print the final tabulations of mean yields, with their standard errors, in the proper units, with a table of the analysis of variance, in such a way that the results could be despatched to the experimenter without any copying and with a minimum of annotation.

To effect this, and to deal with the more complex types of design, such as split plots and factorial designs, and the complications of confounding and estimation of error from high order interactions, programmes of some complexity must be written, and considerable ingenuity has had to be exercised to take account of the variants in design that are commonly met with. By now, however, a library of programmes for experimental analysis has been built up which can take care of the great majority of experiments that are submitted for analysis.

The Department has consequently been able to provide a general service to agricultural and biological research workers for the analysis of experiments. That this is of value is indicated by the rapidly increasing numbers of analyses that are being carried out for other research institutes, both in this country and overseas, and for the National Agricultural Advisory Service. Part of the large increase in the last two years represents the clearing up of backlogs of

Numbers of replicated experiments analysed in the Department

	Number of experiments			Number of variates on computer
	By hand	On computer	Total	
1934	115	—	115	—
1951	437	—	437	—
1955	384	419	803	834
1956	181	683	864	1,701
1957	98	1,253	1,351	5,041
1958	182	1,664	1,846	6,260

results that have been accumulated by research workers who were unable to make arrangements for their analysis. The more than proportionate increase in the number of variates analysed is due to the greater attention that is being paid to supplementary observations.

Experience has shown that once the programmes are completed and the machine work is organised the time lag between the completion of the experiments and their analysis can be very substantially reduced by the use of an electronic computer. This has obvious and very great advantages in research work. There are also secondary advantages. Thus residuals can be easily calculated, covariance analyses can be readily made, and missing values can be allowed for without difficulty. Moreover, the continual burden of training fresh recruits to the computing staff in the intricacies of complex types of analysis is avoided.

An important extension of the analysis of single experiments is the summarisation and analysis of the results of groups of similar experiments. For small groups of experiments this can readily be done on desk machines, but it becomes laborious when the number of experiments is large. A piece of work on these lines at present in progress is the analysis of the results of two hundred and thirty $3 \times 3 \times 3$ fertilizer trials on cultivators' fields in the State of Bihar, India. Organised experimental work of this nature involving hundreds of trials is becoming increasingly common in underdeveloped countries where little is known of such basic facts as the fertilizer requirements of crops grown under cultivators' conditions. The analysis of the results of such trials on desk machines is a formidable task, which frequently leads to long delays and greatly reduces the value of trials.

The organisation on the electronic computer of the analysis of survey results, which constitutes the second major load of routine analysis by the Department, is now being undertaken. The problems here are very different from those involved in the analysis of experiments, but the need for improved and more speedy methods of analysis is pressing, and considerable progress has already been made. In 1957, for example, for the first time, the Survey of Fertilizer Practice was analysed on the machine. The 1957 survey was three times the size of any previous fertilizer practice survey and it was clear from the outset that if the analysis was to be completed in reasonable time it would have to be done on the computer. It was, however, somewhat uncertain whether the computer would

prove really suitable, particularly since it had been found from previous experience, that for this survey edge-punched cards were preferable to the use of punched card machinery. In the event the analysis on the computer proved highly successful. It enabled the results to be obtained far more speedily than had been the case in the past; the results of two districts for which the field data were received on 9th December, for example, were available on 13th December, and were incorporated in a report issued on 19th December. Moreover, contrary to early fears, it was found that a more detailed analysis of special points could be made than was possible with edge-punched cards.

In parallel with the development of the analysis of survey results, which will include both the generalization of computer programmes and the introduction of more thorough methods of analysis than are possible with punched-card machinery, considerable attention will be paid to machine scrutiny of survey and other data. Survey data are from their nature particularly liable to field errors, and thorough checking at the initial stage is required if material errors are to be avoided in the results. Adequate checking of this type was virtually impossible before the introduction of electronic computers.

In addition to surveys there are many other activities in agricultural and biological research that result in the collection of large quantities of numerical data, much of which is at present very inadequately analysed. Here also it is expected that the development of the appropriate methods of data processing on electronic computers may lead to a much better utilization of the information that has been collected.

Analysis of experiments and surveys forms only a part of the present work of the Rothamsted computer. It is actively employed on many other types of computation, ranging from such routine tasks as the fitting of probit lines to long and elaborate pieces of computation required for the solution of special problems which could not have been tackled before the introduction of computers. Thus it has been used to calculate the effects on population numbers of the introduction of sterile males into populations of tsetse flies; it is believed that female flies only mate once and are thus in effect sterilized by mating with a sterile male¹. A number of genetical problems, such as the effect of inbreeding with selection and linkage², and the estimation of linkage from human pedigree data³, have been tackled. A great deal of multivariate work, ranging from the calculation of variance-covariance and correlation matrices and standard multiple regression analyses to discriminant function and principal component analysis has been undertaken; for example, a controversy on the classification of certain fossil teeth from a comparison with measurements on the teeth of humans and the great apes was resolved⁴, and recently the computer has been used to construct from multiple measurements on apple trees a few simple criteria representing size and habit of growth. The computer has been extensively used also for fitting curves required in growth studies of various kinds. It has also been used for certain non-statistical computations, in particular crystallographic work for the Pedology Department at Rothamsted⁵.

One important advantage of the introduction of electronic methods of computation in research statistics is that once the appropriate type of analysis has been evolved, and the necessary programmes written, all available bodies of data of the same type can be readily processed. In the past many statistical investigations have suffered from the defect that conclusions have been based on the analysis of a single body of data, for the reason that, although there have been other bodies of data available, the labour of computation has deterred the original investigator from undertaking the work. This is particularly unfortunate in that one of the best tests of the validity of conclusions is their consistency over

similar sets of data. Moreover, variation in the effects observed in different circumstances often gives further indication of the nature of the phenomena under investigation which no amount of study of a single set of data would reveal.

The history of the investigation of the influence of rainfall on crop yields, using the accumulated data from the permanent manurial trials at Rothamsted and elsewhere, provides an illustration of these points. In the early 1920's R. A. Fisher evolved a most elegant method to deal with this problem, and applied it to 60 years' data from the permanent wheat manurial trial at Rothamsted (Broadbalk field)⁶. Suitable data from a number of other similar trials were also available, but not unnaturally, in view of the very lengthy computations required, Fisher did not himself attempt any further analyses. From time to time, however, various other workers were given the task of carrying out such analyses. In the event it took just on twenty years for all available sets of data to be processed in this manner, and unfortunately as the investigations progressed it became only too apparent that the results from different fields carrying the same crop were by no means concordant. Had an electronic computer been available it could easily have been used to carry out the whole of the computations, since the method is in essence a combination of straightforward regression techniques. If this had been done for the original Broadbalk investigation there is little doubt that, in view of the encouraging results, all other available data would have been immediately analysed. The investigation might well also have been extended to include factors other than rainfall; as it is, only one very partial investigation on the effect of sunshine has been carried out, and temperature has never been examined.

Summing up, it may be concluded that electronic methods of computation will in time be adopted for all the heavier types of computation in research statistics. The process of change is, however, likely to be gradual, since the writing of specific programmes and the organisation of the flow of work on a computer is a lengthy and involved task. Somewhat surprisingly, also, it has been found that the present generation of statisticians is decidedly resistant to the introduction of electronic methods of computation. This may be due in part to the failure of statisticians to appreciate the full potentialities of computers, in part to their reluctance to accept, and to adapt themselves to, centralisation of the computational part of their work. There are, however, two genuine grounds for caution. First, computation on desk machines is undoubtedly the ideal way to gain a thorough appreciation of the data, and may well bring to light special features and defects that might otherwise escape notice; there will in fact always be a place for pilot computations on desk machines carried out personally by skilled statisticians. Secondly, decisions on what course to follow in the later stages of an analysis are frequently best made after consideration of the results emerging from the earlier stages; this difficulty can be overcome by running the analysis in stages and returning the results for examination at each stage.

The question of how electronic computational facilities can best be organised so as to be readily available to statisticians is one to which no final answer can be given. For effective work on the lines already described a computer of a certain minimum size must be employed, and the cost of maintaining such a computer, and the amount of work it can handle, are such that a considerable degree of centralisation is essential if it is to be solely or mainly occupied on statistical work. The alternative is for research statisticians to make use of some computer situated in their neighbourhood which is occupied for much of its time on non-statistical work. Now that many universities are acquiring computers direct access to one of them will certainly be possible for many research workers.

In fact, however, to carry out effective statistical work on a computer much more is required than mere access to a machine. From the experience gained so far it would seem likely that it will be best to arrange for the major part of the electronic computations required by research statisticians to be dealt with at a few centres specialising in this work. Each such centre would be able to carry a group of workers who between them would have wide statistical experience, and who would be thoroughly familiar with the available programmes, and who could modify them and write new programmes as need arose, together with adequate staff and equipment for the punching of data and the general organisation of the work. Such centres would be able to provide facilities for statisticians at other institutes who desired to programme some of their own problems; in general this task is much easier on a machine for which a good library of basic programmes in the statistical field is already available, and when there is contact with a computer group which is already familiar with these programmes and with the handling of similar problems. It is significant that the Rothamsted computer is the only computer in this country that has as yet an adequate set of programmes for those fields of research statistics which are its special province.

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² REEVE, E. C. R. and GOWER, J. C., 1958, *Proc.Int.Symp. on Biometrical Genetics*.

³ SIMPSON, H. R., 1958, *Ann.Hum.Genet.*, **22**, 356-61.

⁴ ASHTON, E. H., HEALY, M. J. R. and LIPTON, S., 1957, *Proc.Roy.Soc.B.*, **146**, 552-572.

⁵ GOWER, J. C. and RAYNER, J. H., 1958, *Brit.J.appl.Phys.* **9**, 446.

⁶ FISHER, R. A., 1924, *Philos. Trans. B*, **213**, 89-142.

TRACE ELEMENT DEFICIENCIES IN CROPS

The trace elements that have been shown to be essential for the nutrition of higher plants, including crop plants, are boron, copper, iron, manganese, molybdenum, zinc and chlorine. (Of these chlorine, as chloride, has only recently been added to the list and the special effects resulting from a deficiency of it in crop plants, other than tomato, have not yet been established.) This list is not regarded as final, but it is very difficult to prove that elements present only in trace amounts are *essential* in any given case, and if other elements are eventually added to the list their discovery will come only after considerable experimental work, based on highly refined methods. The difficulties entailed in the work will be apparent from the fact that to prove the essential role of molybdenum in some crop plants it has been necessary to work with nutrient solutions having molybdenum contents of one part in every twenty thousand million, and to ensure that containers, water and chemicals contained sufficiently low amounts of molybdenum throughout the life cycles of the test plants to maintain these extremely low levels.

In addition to the trace elements already established as essential nutrients, there are major elements, such as aluminium and silicon, that are regarded as beneficial for special plants, and in special cases their addition to nutrient media may lead to increased yields or other favourable growth effects. Again there are others, not yet proved to be essential for higher plants in spite of numerous experiments. There is, for example, cobalt which is a well established essential nutrient for animals. There is also vanadium, already shown to be essential for lower forms of plant life (e.g. the alga *Scenedesmus*) and to be capable of replacing molybdenum as a catalyst in the process of nitrogen fixation by *Azotobacter* and *Clostridium*. In two pasture trials in New Zealand the growth responses of

the herbage to dressings of ammonium vanadate at 3 oz. per acre were similar to those to sodium molybdate at $2\frac{1}{2}$ oz. per acre, but even results such as this do not provide the critical evidence needed to add vanadium to the list of essential trace elements. Whilst it seems probable that vanadium and other elements may eventually be added to the list, more refined experimental methods than are available at present will be necessary, because the culture solution method, which has been used so effectively in the past to establish the essential nature of mineral nutrients, seems to have reached or to be approaching its effective limits of usefulness for this purpose.

It seems likely that further advances in this field will come through the application of newer biochemical techniques in functional studies of elements, particularly in connection with the mechanism of enzyme systems. This functional approach, it may be noted, is not a new idea, for as early as 1897 Bertrand had reported manganese as consistently associated with the activity of the oxidising enzyme laccase (now known to be dependent on copper and not manganese), and at a later stage he was able to suggest that manganese was an essential nutrient for the fungus *Aspergillus*.

THE EFFECTS OF TRACE ELEMENT DEFICIENCIES ON CROP PRODUCTION

With the exception of chlorine, deficiencies of each of the trace elements have been shown to be of importance in limiting yields or injuring the quality of a great variety of crops, often to the extent of causing total losses. A recent experiment with herbage plants in California suggests that chlorine may be of importance on certain soils in that state. Deficiency of the element would not, however, be expected to be widespread owing to the occurrence of "cyclic salt" in the atmosphere over large areas of the world.

The specific effects that result on various crops have been described and portrayed in many worldwide publications^{1,2}, and by these means symptoms of deficiencies have become well known to growers of susceptible crops in areas likely to be affected. A reasonable assessment of the possible and actual losses in crop production due to deficiencies of trace elements is practically impossible, since where they are known to occur in important crops on any great scale, routine measures are taken for their prevention, whilst in more backward farming areas the deficiencies generally remain unidentified or the standard of farming is often so low that the effects of the trace elements cannot be separated from those of other factors. It may be stated, however, that the deficiencies are important in both tropical and temperate region crops, and their importance in the tropics is likely to increase as production is intensified. Already a considerable amount of knowledge has been gained for crops such as oil palms, ground nuts, cotton, tea and rubber^{3,4}.

A point of note in connection with trace element deficiencies is the special importance of individual elements for particular crops, e.g. boron for sugar beet, manganese for oats, iron for tree crops, copper for cereals, zinc for Citrus, and molybdenum for pasture and Brassica crops.

From the literature and from a recent questionnaire it would seem that in the world generally, as in Great Britain, the most prevalent trace element deficiencies of crops are boron and manganese, though in local areas of special crops and soil conditions deficiencies of one or more of the other elements may assume greatest importance. Chlorine deficiency does not occur in Great Britain.

SOIL CONDITIONS AND TRACE ELEMENT DEFICIENCIES

Whilst the varying susceptibilities of crops to trace element deficiencies in some instances overshadow their relationships to soil conditions, nevertheless surveys and reports from widely separated areas of the world have shown that

deficiencies of each element can often be related to special soil conditions. These special conditions may result primarily from the original nature of the parent materials from which the soils were formed, or from the climatic and other conditions under which the soils were developed, or they may have been to a great extent induced by farming practices.

Important relationships that have been observed are as follows: the prevalence of boron deficiency on calcareous soils and on highly leached, poor sandy soils, derived from siliceous or ancient rocks; copper deficiency on reclaimed podzolic soils of heather moors, and on poor calcareous sands and on some peats; iron deficiency on most calcareous soils when tree crops are grown; manganese deficiency on calcareous soils, particularly where organic matter is high and when drainage is defective or the watertable high; manganese may become highly available in acid soils and reach toxic levels for crops; molybdenum deficiency occurs mainly on strongly leached acid soils and on ironstone soils, and availability may rise to levels toxic to livestock, though not to crops, on calcareous soils; zinc deficiency has not been closely associated with any naturally occurring soil conditions, but has been induced by excessively high organic matter in corrals in North America.

Soil reaction is a most important factor in influencing the availability of trace elements in soils. Deficiencies of boron, iron, manganese, copper and zinc may all be induced by excessive liming, whilst molybdenum availability is increased by lime applications. No data exist for chlorine, but it is improbable that pH differences and liming practices will affect its availability.

A notable attempt to map the occurrence of trace element deficiencies and excesses in U.S.A. and to relate these to some extent to soil conditions, has been made by Beeson⁵, and interesting correlations have been established by workers in New Zealand^{6,7}.

In Great Britain the soil pattern in relation to the occurrence of the various deficiencies conforms to the general world pattern. Boron deficiency is associated mainly with chalky and other calcareous soils and with poor sandy soils and soils developed on the older rock formations, and with Fen peats. Iron deficiency, which is only of importance in tree crops and some horticultural plants, occurs only on calcareous soils. Manganese deficiency is generally confined to soils with pH higher than 6.5, often either naturally highly calcareous soils or soil previously acid and heavily limed. Organic matter is generally high, the soil colour often blackish, and drainage impeded or the natural watertable high. Typical areas are the Fens, high watertable soils, as in Romney Marsh and in some alluvial flats, e.g. around Bridgwater in Somerset, and reclaimed and limed podzolic soils in the West Midlands. Copper deficiency has been of greatest importance on some of the East Anglian peats and heaths and in some areas on the Old Red Sandstone formation in Scotland. Isolated instances in fruit trees have been recorded on sandy soils of low fertility in the south of England. Zinc deficiency has been restricted to a few cases in fruit trees, mainly apples and pears, with no clear relationships with soil conditions in evidence.

Molybdenum deficiency has been restricted to Brassica crops, mainly cauliflower, and to a few instances in lettuce, the soils at most centres being clearly of the leached podzolic types. The most notable instances of the deficiency have occurred in the important market garden areas.

THE DIAGNOSIS AND CONTROL OF TRACE ELEMENT DEFICIENCIES

Several methods are available for the diagnosis of trace element deficiencies and in practice it is customary to combine two or more of these to ensure a correct diagnosis¹.

The main methods in use are as follows:—

- (1) Visual diagnosis in which the deficiencies are recognised by characteristic effects shown by certain crop plants. The symptoms that may be used have been depicted in colour and black and white for a large number of crops and keys devised to aid in the diagnosis.
- (2) Foliar spraying and injection methods. These depend for their effectiveness on the fact that plants deficient in one or more of the trace elements will respond quickly when the deficient elements are supplied in appropriate solutions at suitable stages of growth.
- (3) Leaf analysis. The deficiencies are reflected in the composition of various organs of the plants, especially the leaves, and can be detected by making comparisons between comparable healthy and deficient plants. Rapid chemical tests for direct application to leaves and stems have been devised.
- (4) Soil analysis. Soil tests, analogous to leaf analysis, have also been developed, usually involving extraction with water, dilute acids or solutions of chelating agents.

A biological method in which the fungus *Aspergillus niger* is used is very effective, its suitability for the purpose depending on the fact that the requirements of the fungus for most of the trace elements parallel those of crop plants, and that it is quite sensitive to the very small differences involved in trace element problems.

The above methods are generally used in making preliminary tests and may form the basis of subsequent quantitative field trials. In most cases under examination the tests are combined with field observations of the general soil conditions, in particular of soil type, pH, organic matter content and drainage. When these methods are used by experienced advisers there are few instances of trace element deficiencies that will not be readily and correctly diagnosed. This is certainly true for Great Britain.

Much attention has been given to methods of preventing and curing trace element deficiencies, and at the present time effective treatments are available for all the elements with the exception of iron, for which improvements are still desirable. For some of the elements soil dressings of fertilisers containing the deficient element are generally ineffective, and it is necessary to supply them by means of foliage sprays. The following summarises the position for the various elements:

Boron is usually effective as a soil dressing in the form of borax at 20 to 40 lb. per acre. Foliage sprays at 10 to 20 lb. borax plus spreader per 100 gallons per acre may also be applied to farm crops or at 3 lb. per 100 gallons for tree crops.

Manganese may be ineffective as a soil dressing, but foliage sprays are generally very efficient, especially when applied at an early stage in the growth cycle; for the control of Marsh Spot in peas, which affects the seeds, the spray must be applied during the flowering period. The usual spray for farm crops consists of 10 lb. manganese sulphate plus spreader per 100 gallons per acre, and for tree crops the concentration is 3 lb. per 100 gallons. Soil dressings, which have been reported as giving some control in soils, have usually been of manganese sulphate at 20 to 40 lb. or more per acre, sometimes applied with sulphur to decrease soil alkalinity.

Iron applied to the soil is rarely effective in correcting chlorosis although, in exceptional cases where the condition occurs on acid soil, it has been corrected by dressings of suitable chelate compounds of iron. The usual method of control (generally used only on horticultural crops, especially tree crops) is by

foliar sprays of iron at about 1 lb. per 100 gallons. Inorganic iron salts, such as ferrous sulphate, are much less effective than the organic chelate compounds. The iron position is not regarded as satisfactory since results are often very temporary and uncertain, and the iron applied through the leaf does not move freely through the plant tissues in the way other trace elements do.

Methods are also available for applying manganese and iron to tree crops by stem injections of the respective sulphates.

Copper may be applied either as soil dressings or foliage sprays of copper sulphate and other copper containing materials. Effective soil dressings vary widely from 5 lb. to 50 lb. or more of copper sulphate, according to the soil conditions. The higher rates are likely to be required on soils with high contents of lime or organic matter. Copper sprays are liable to injure the leaves and copper sulphate may have to be used at a concentration as low as 1 lb. per 100 gallons. The concentration may be raised considerably by using basic compounds such as Bordeaux Mixture.

Zinc may be effectively used as a soil dressing on some soils and zinc sulphate has been used at rates from 7 lb. per acre on coarse sands to 60 lb. per acre on heavy soils. Soil dressings may be relatively ineffective on soils with high organic matter content, and availability is also low on calcareous soils. Foliage sprays of 3 lb. zinc sulphate plus spreader per 100 gallons are suitable for tree crops and if damage is feared $1\frac{1}{2}$ lb. of slaked lime may be added to the above solution. For deciduous trees, winter sprays of 20 to 40 lb. zinc sulphate per 100 gallons, applied to the trunks and branches, are effective.

Molybdenum may be applied as sodium or ammonium molybdate, either as soil dressing or as a foliage spray, at rates from 1 lb. to 2 lb. per acre. On some soils, rates as low as 4 oz. per acre have sufficed for pasture plants. Crops respond readily to these treatments.

Chlorine deficiency can be cured by application of any of the usual chloride-containing fertilizers used at the normal rates and should not present any special problems.

FUNCTIONS OF TRACE ELEMENTS

Whilst the nature of the practical agricultural aspects of trace element deficiencies in crops are now well known, and efficient guidance can be given to farmers to prevent losses from them, knowledge of the functions of trace elements in the metabolic processes of plants is still very limited. In a general way the trace elements may be stated to function as catalysts in enzyme systems, but their many and special roles will only become clear as the result of long and complicated biochemical investigations.

Among the roles that have been assigned to the individual elements the following may be mentioned:

Boron. One of the most recent suggestions is that it has a specific role in the translocation of sugars; this is stated to be in keeping with a common symptom of boron deficiency, the death of growing points. Boron also appears to play an essential role in reproduction and the germination of pollen, and it has been claimed that it may affect the solubility of calcium, water relationships in plant tissues, and certain functions of plant hormones.

Iron. An outstanding feature of iron is that, although not a constituent of chlorophyll, it is closely concerned with its formation. It is the important mineral element constituent of the closely analogous compound haematin, which occurs along with chlorophyll in leaves. In recent investigations at Long Ashton it has been shown that a close relationship exists between the amounts

of chlorophyll and haematin when progressive degrees of chlorosis are produced by varying the severity of iron deficiency.

Iron is also an essential constituent of the enzymes catalase and peroxidase, and of cytochromes b and c concerned in respiration, and along with copper is active in nitrite and hyponitrite reductases.

Manganese. Like iron, manganese appears to have some function associated with chlorophyll formation, but results at Long Ashton suggest that the functions differ. Iron and manganese show antagonistic properties in plants, and an excess of either can lead to a deficiency of the other. The main functions of manganese are likely to be concerned with oxidation/reduction reactions. It has been shown to be an essential metal in hydroxylamine reductase and in prolidase.

Copper. Copper is an essential metallic constituent of a number of enzymes concerned in oxidation/reduction reactions, and is of particular importance in reactions involving the oxidation of polyphenols, as in tyrosinase and laccase. It also occurs in ascorbic acid oxidase and along with iron in nitrite and hydroxylamine reductases.

Zinc. Zinc is also an essential metal in many oxidation/reduction enzyme systems, examples of which are alcohol, glutamic and lactic dehydrogenases, and is also a constituent of carbonic anhydrase and glycyl glycine dipeptase. Recently it has been shown to be an essential metal constituent, along with magnesium, of hexokinase.

Molybdenum. Molybdenum has been shown to be essential in the reduction of nitrate in plants and in the fixation of nitrogen by legumes. In the former case it has been shown to be a constituent of nitrate reductase. Deficiency of molybdenum in Brassicas also results in low contents of ascorbic acid in the leaves, and, moreover, crop plants given ammonia and other forms of nitrogen for their nutrition continue to show some of the typical symptoms of molybdenum deficiency, e.g. Whiptail in cauliflower. It is thus apparent that the element performs enzymatic roles in higher plants other than in nitrate reductase. Molybdenum also functions with iron in hydrogenase, and xanthine and aldehyde oxidases.

Chlorine. The essential nature of chlorine in specific enzyme reactions has not been established as for the other trace elements. It has been shown, however, that the chloride ion may speed up photosynthesis *in vitro*, although it has not been proved to be essential to the process.

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TRACE ELEMENTS IN ANIMALS

While an analysis of the bodies of animals reveals the presence of practically all the known elements, not all of these have as yet been proved to be essential for life. When an element in the body is found in relatively high concentration it can be presumed that it is essential to maintain normal growth and reproduction and it is usually easy to devise a diet or test which will prove this essentiality. In this class are such nutrients as carbon, hydrogen, oxygen, nitrogen, sulphur, calcium, phosphorus, magnesium, potassium, sodium and chlorine. These are termed the macronutrient elements. In contrast there are other elements whose essentiality has been brought to light by closer investigation, generally through the occurrence of deficiency diseases and their relief by the application of the missing element. Such elements are required in very small amounts and constitute micronutrients or "trace elements". Into this group we place iron, copper, cobalt, zinc, manganese, molybdenum, iodine, and possibly selenium, fluorine and arsenic. Trace elements are of great importance and have been the subject of many reviews.

Where metals in traces form essential parts of enzyme systems in the animal body they *ipso facto* become essential nutrients for that animal. Molybdenum is essential for certain animal enzyme systems but it is doubtful whether a diet sufficiently deficient in this element to cause deficient growth has yet been devised. Manganese fell into the same category for some time, although it was known to be an essential element in at least one enzyme system, and it is still not easy to produce a syndrome of manganese deficiency. In young chicks shortening of the leg and wing bones and also perosis or slipped tendon can occur when manganese is deficient. Although at least 23 enzyme systems are known to be activated *in vitro* by manganese, only two of these have been shown to have a specific requirement for manganese *in vivo*.

So far as is known, iodine is not required by plants and boron and vanadium are not required by animals though vanadium is accumulated by Ascidians and may replace iron or copper in the respiratory pigments of these animals.

The fact that the trace elements are needed in only small quantities suggests that they are functioning in some catalytic role. Except for iodine which is an essential constituent of the thyroglobulin molecule secreted by the thyroid gland, and cobalt which is at the core of the vitamin B₁₂ molecule, a known enzymic function has been described for most of the other trace elements. Iron has in addition other functions in higher animals as an essential part of the respiratory pigment haemoglobin; copper or vanadium play a similar role in some lower animals.

The recognition of trace element deficiencies in stock—often associated with a wasting condition—and their treatment has opened up possibilities of increased animal production not only in this country but to a much greater extent in Australia where the increase in value of wool and fat lambs is of the order of £30 million a year and in New Zealand of something like £18 million.

INDIVIDUAL ESSENTIAL TRACE ELEMENTS

Iron

Most of the iron in the body is present as haemoglobin, and a deficiency is shown by an anaemia. Iron is abundant in the soil and there is no risk of iron deficiency where livestock have access to soil or are grazing. In rapidly growing sucking animals however the mother's milk may contain insufficient iron and anaemia may readily occur.

A conditioned deficiency of iron has been brought about in some laboratory animals by feeding too much calcium carbonate in the diet but as magnesium

carbonate produces the same effect it is believed to be due to the carbonate ion interfering with the absorption of the iron. The rat absorbs as much iron given in the ferric state as in the ferrous state because of the presence of reducing substances in the diet.

It has been suggested that the minimum requirements for maintaining normal haemoglobin in calves is 30 mg. daily.

Copper and Molybdenum

The factors influencing copper utilization by the animal are imperfectly understood. There is, as yet, no fully satisfactory explanation of many outbreaks of copper deficiency disorders of cattle and sheep in Britain. In these instances the copper intake of the grazing animal is apparently in excess of that considered necessary to produce a deficiency in other regions. It has been clearly established in Australia that copper utilization in the ruminant may be impaired if the molybdenum and sulphate content of the diet is elevated¹ and many aspects of this work have been confirmed in studies subsequently carried out in Britain.² Field studies in Britain have, however, failed so far to establish clearly that many cases of "swayback" in sheep and unthriftiness in calves and adult cattle, known to be preventable by copper therapy, are associated with elevated levels of inorganic sulphate in herbage when pasture molybdenum is also high. The mechanisms underlying the interference to copper metabolism caused by molybdenum and sulphate are being examined. It has been found that as the sulphate content of the diet increases so does the extent of sulphide production in the rumen. This change is accompanied by a decrease in the content of soluble copper in the rumen and abomasum and the magnitude of this change is increased if molybdenum is simultaneously fed³. Since sulphide in the rumen can arise both by reduction of inorganic sulphate and by enzymic action on sulphur-containing amino acids, it is possible that the level of these amino acids in dietary proteins may also have an influence on copper availability. In studies with the rat it has been found that high levels of dietary molybdenum interfere with the metabolism of sulphide in the liver by partially inhibiting the action of the enzyme sulphide oxidase⁴. Other studies carried out by Allcroft and her associates have indicated that when the copper status of the pregnant ewe is low, the copper content of the foetal liver can be decreased by increasing the sulphate content of the diet⁵.

The use of copper in the diet of fattening pigs has been extensively investigated. In one series of experiments carried out at 8 different centres the addition of 250 parts per million of copper to the diet significantly increased the growth rate up to bacon weight⁶. In a further trial, employing supplementary levels of copper ranging from 30 to 500 p.p.m., the rate of gain and efficiency of food conversion from 8 weeks of age to 200 lb. weight was greatest in groups receiving 125 p.p.m. copper⁷. The copper content of the livers of these animals ranged from 37 to 540 p.p.m.; in animals receiving 500 p.p.m. copper supplement the liver copper values were in the very high range of 1,700 to 4,600 p.p.m.

In studies of the effects of copper deficiency on the pig, the concentrations of cytochrome oxidase in the liver and heart and the activity of catalase in the liver have all been found to fall. The excretion of allantoin and uric acid in the urine were increased.

The therapeutic value of parenteral injections of copper glycine for the control of copper deficiency in the field is being extensively studied⁸. Intramuscular injection of this compound into cattle has been shown to lead to cyst formation and subcutaneous injection into the brisket appears to be the most suitable method of administration. Good control of "swayback" in sheep has been obtained by subcutaneous injection of ewes at mid-pregnancy with 50 mg.

copper as the glycine complex. Toxicity trials with sheep suggest that such injections should not be carried out unless the copper status of the flock is known to be low. Similar experiments with cattle indicate a somewhat greater tolerance.

Work on chicks and turkey poult fed synthetic diets has suggested that a deficiency of molybdenum may have an adverse effect on growth; this was accompanied by a decrease in the activity of xanthine oxidase in the liver but precise interpretation of this work is difficult because the quantity of molybdenum added to the diet was small in relation to that which the basic diet contained.

Cobalt

It is now well established that the "pining" condition of sheep maintained on cobalt deficient pastures may be completely prevented by injection of relatively large amounts of the cobalt-containing vitamin B₁₂^{9,10}—a fact which strongly supports the hypothesis that the syndrome of cobalt deficiency is solely the result of a failure of vitamin B₁₂ synthesis by rumen micro-organisms consequent upon an inadequate supply of cobalt reaching the rumen.

In the control of cobalt deficiency in the field an important advance has been made by the introduction, for oral administration, of heavy pellets containing baked clay and cobaltic oxide; these remain in the reticulum and slowly liberate sufficient cobalt to meet the requirements of sheep and cattle¹¹. The specific gravity and size of such pellets is critical if they are to be retained; using pellets of specific gravity 4.1–4.5 a high measure of control of field outbreaks of cobalt deficiency has been obtained both in Australia and Britain.

This method of control may be of value in the protection of sheep against "phalaris staggers"—a condition reported from Australia and New Zealand in which a progressive paralysis results from the ingestion of a toxic principle present in pasture containing *Phalaris tuberosa*. The condition may be prevented by repeated oral administration of cobalt salts¹² but unlike cobalt pine, cannot be prevented by vitamin B₁₂ injection. It is therefore presumed either, that cobalt stimulates the proliferation of organisms in the rumen that degrade the toxic principle, or that it has a direct effect in preventing degeneration of nervous tissue. It is of interest that evidence now suggests that cobalt plays a direct part in the metabolism of nervous tissue *in vitro*¹³.

In other species the metabolic role of vitamin B₁₂ and cobalt-containing compounds of similar structure is being investigated. It has been found that a number of vitamin B₁₂ analogues (pseudo-vitamin B₁₂, factors B & D) antagonise the growth stimulatory effects of B₁₂ supplements fed to deficient chicks. It has recently been suggested that vitamin B₁₂ may play a part in the incorporation of amino acids into tissue protein.

Manganese

Disorders in grazing animals due to manganese deficiency in the herbage have not yet been established as the deficiency level lies below 20 p.p.m. Depression of growth can occur with excess of this element; there is some evidence which suggests that in lambs manganese in excess seems to convert iron to a form which is physiologically unavailable or affects its absorption.

A deficiency of manganese can be produced experimentally in growing pigs and causes bowing and shortening of the front legs and lameness owing to an early cessation of ossification of the radius and ulna. Defective bone formation due to deficiency of this element has also been found in birds while lowered egg production and decreased hatchability of the eggs also occur. The higher manganese requirement of birds compared with mammals is partly due to a lower absorption from the gut. A lack of manganese reduces the activities of certain bone enzymes.

Zinc

There is a condition of severe dermatitis in pigs (parakeratosis), associated with diarrhoea and weight loss which can be prevented by the addition of zinc salts to the ration¹⁴. A lead to this discovery was the fact that parakeratosis was readily induced on dry meal diets by increasing the calcium content of the ration by supplements of bone meal or calcium carbonate; this suggested, by analogy with previous experience on manganese utilization by poultry and on iron utilization by rats, that trace element utilization had been impaired. The action of calcium has been further studied¹⁵ and the results showed that on high calcium rations (1.1–1.4 per cent Ca) the addition of 50 p.p.m. zinc to a ration already containing 35 p.p.m. was not sufficient to prevent completely the appearance of parakeratosis. Dramatic recovery of established cases was obtained using 100 p.p.m. supplementary zinc. Decreases in the zinc content of liver and kidney were noted when 2 per cent bone meal was added to rations containing 85 p.p.m. zinc.

Again it has been shown¹⁶ that the growth of pigs between 9 and 16 weeks of age, maintained on a dry meal containing 1.3 per cent calcium and 0.7 per cent phosphorus, was significantly improved by adding 100 p.p.m. zinc. Parakeratosis is less common where wet feeding is practised, a possible explanation of this observation being that sufficient zinc is dissolved from the galvanized feed troughs to meet zinc requirement. On the other hand, it has been found that the beneficial effect of wet feeding was maintained even though the meal never came in contact with metal troughs¹⁷.

Zinc deficiency has been produced in chicks and turkey poults but normal exposure of birds to the zinc coating of battery cages should be sufficient to prevent the deficiency occurring under practical conditions.

Selenium

Following recent work on liver necrosis in rats, fed diets containing yeast or some purified caseins, has come the discovery that selenium can protect against degenerative changes brought about by diets low in vitamin E and cystine. Selenium (as selenite) has been found to be 500 times as active as vitamin E and 2,500 times as active as cystine in this respect. Exudative diathesis in chicks fed yeast diets low in vitamin E was found to be prevented if 0.3 p.p.m. selenium was included. A wide range of organic selenium compounds has been examined for potency in protecting against liver necrosis in the rat¹⁸ and exudative diathesis in the chick¹⁹ but none of these materials had as high a potency as a selenium-containing fraction made from the pig kidney.

No beneficial effects on growth of chicks were obtained following supplementation of diets adequate in vitamin E with 0.2 or 1.8 p.p.m. selenium²⁰. Other results obtained with diets "borderline" with respect to vitamin E requirement suggest that the addition of 0.1 p.p.m. selenium may improve the growth rate of chicks²¹.

The influence of selenium supplementation on the development of other symptoms of vitamin E deficiency has been examined. Selenium is ineffective in preventing the fall in the storage of vitamin A in the liver, the depigmentation of the incisor teeth and the discoloration of body fat, which occur in vitamin E deficient rats, nor can it restore their reproductive capacity. It has no effect on encephalomalacia in chicks or on muscular degeneration in rabbits. Muscular degeneration ("white muscle disease") in the chick has been prevented by the inclusion of relatively high levels (5 p.p.m.) of selenium in the diet and a similar protective effect against muscular dystrophy in lambs was obtained by adding 1 p.p.m. selenium. Since most of the nutritional disorders so far reported as being preventable by selenium administration do not appear if the vitamin E

level of the diet is adequate, it is doubtful whether the inclusion of selenium is necessary or even desirable especially as there is evidence which suggests that as little as 5 or 10 p.p.m. selenium can cause marked growth retardation and toxicosis in many species.

Iodine

Although iodine is required in traces throughout life to keep the thyroid gland functioning, the minimum requirements are not known; the need is greatest during reproduction. Deficiency in an area gives rise to endemic goitre and, in the young, to cretinism.

The iodine content of the soil is generally reflected in the iodine content of the crops grown. Animals absorb the iodides of sodium and potassium with extreme rapidity and iodine is also absorbed from the skin and lungs. Crude salt contains traces of iodine and this, or iodised salt, is in general use by raisers of livestock in iodine-deficient regions. Excess must however be avoided, particularly by ruminants.

Fluorine

Although fluorine is normally found in traces in plant and animal tissues there is no clear evidence that it is a micro-nutrient for either. Excessive amounts of fluorine are toxic and give rise to "fluorosis" characterised in cattle by lameness and by the presence of marked skeletal abnormalities which are usually the first indication of abnormality and are useful in diagnosis. A number of industries which liberate fluorine compounds into the air and so contaminate the adjacent herbage have an effect on local agricultural production²².

These industries are:—

- (i) aluminium works where cryolite is used as a flux:
- (ii) brick works where the clay is rich in fluorine:
- (iii) glass, enamel and colour works using fluorine compounds:
- (iv) calcining of ironstone rich in fluorine:
- (v) collieries and power stations where low-grade coal containing fluorine-rich shale is used:
- (vi) potteries, where the source of fluorine is the clay and possibly also the coal being used.

Bromine

There are some pointers to a requirement for bromine by young birds and it has been suggested that it may be one of the unidentified growth constituents of dried liver, fish solubles, whey, grass juice and distillers' dried solubles.

Arsenic

Several workers have demonstrated growth-stimulating effects of dietary arsenic in birds.

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- ¹⁹ SCHWARZ, K., BIERI, J. G., BRIGGS, G. M. and SCOTT, M. L., 1957, *Proc. Soc. Exp. Biol. Med.* **95**, 621.
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- ²¹ NESHEIM, M. C. and SCOTT, M. L. 1957, *Ibid.* 48.
- ²² ALLCROFT, R., 1956, *Advancement of Science*, **12**, 494.

RESEARCH STUDENTSHIPS AND FELLOWSHIPS

(a) RESEARCH STUDENTSHIPS

Thirty post graduate studentships, open to honours graduates in science or those holding a veterinary qualification and to graduates in agriculture or horticulture who have shown special interest in one of the basic sciences, were again offered in 1957. These awards are intended to enable young graduates who wish to make a career in research either to take a further course of study, or to undertake a specific research project under supervision as a means of training in research methods, or to read for a veterinary degree in order to equip themselves for research in fields in which this added qualification is likely to be of particular advantage.

The following awards were made in 1957:

<i>Name</i>	<i>Place of Tenure</i>	<i>Subject</i>
I. D. Aitken ...	Glasgow University ...	Animal Pathology
H. C. Bennet-Clark ...	Cambridge University ...	Insect Physiology
R. G. B. Brown ...	Oxford University ...	Animal Behaviour
A. G. Callely ...	Leeds University ...	Biochemistry
B. G. Carter ...	Institute of Animal Physiology	Biochemistry
P. J. Casselton ...	London University ...	Plant Physiology
C. H. Clarke ...	Birmingham University ...	Microbiology
D. W. G. Clements ...	London University ...	Plant Nematology
B. J. Deverall ...	London University ...	Plant Pathology
R. O. D. Dixon ...	London University ...	Plant Biochemistry
A. F. Dyer ...	Oxford University ...	Plant Genetics
B. Frankland ...	Manchester University ...	Plant Physiology
T. F. Hering ...	Cambridge University ...	Plant Pathology
J. McC. Howell ...	Royal Veterinary College ...	Animal Pathology
A. S. Jones ...	Rowett Research Institute ...	Animal Nutrition
M. Kelly ...	London University ...	Biochemistry
J. M. King ...	Cambridge University ...	Parasitology
C. N. Law ...	University College, Aberystwyth.	Plant Genetics
A. P. Mainwaring ...	London University ...	Entomology
E. I. Mercer ...	Liverpool University ...	Biochemistry
B. V. H. Milborrow ...	London University ...	Plant Physiology
T. A. Miller ...	Glasgow University ...	Veterinary Studentship
S. A. Pearce, Miss ...	Oxford University ...	Animal Genetics
R. J. Poole ...	Birmingham University ...	Plant Physiology
J. L. Readshaw ...	King's College, Newcastle ...	Insect Ecology
M. T. Tanton ...	London University ...	Entomology
P. D. Walker ...	Leeds University ...	Bacteriology
D. C. Watts ...	London University ...	Comparative Biochemistry

At 31st March, 1958, the number of students in training was 71, divided amongst the different disciplines as follows:—

<i>Botany</i>	<i>Chemistry</i>	<i>Entomology</i>	<i>Zoology and Veterinary Science</i>
21	17	13	20

(b) FELLOWSHIPS

Junior Agricultural Research Fellowships are offered by the Council to provide opportunities for young scientists of outstanding ability, who have completed not less than three years' post graduate work, to undertake independent research before seeking an appointment in a research institute or elsewhere. Three of these awards, tenable for a maximum period of three years, are available annually; since 1950 nine Fellowships have been granted. Those current at 31st March, 1958, were:

P. Andrews, B.Sc., Ph.D.	...	Bristol University	...	A study of the biosynthesis of certain plant polysaccharides.
J. G. Shoesmith, B.Sc., Ph.D.		Manchester University		Research on the biochemical aspects of bacterial motility.
W. D. Stein, M.Sc.	...	London University	...	Research on the mechanism of facilitated diffusion in the red blood cell.

Veterinary Research Fellowships are offered to enable veterinary graduates with not less than three years' post graduate experience, to continue their researches for a further period of up to three years before seeking a post. There were none current at 31st March, 1958.

SPECIAL RESEARCH GRANTS

During the period covered by this report the Council have continued to make grants to Universities, Colleges and other organisations, to assist in research projects on subjects of interest to the Council. Grants are normally limited to three years but occasionally they are made for longer periods.

The grants current on 31st March, 1958, were as follows:—

1. ABERDEEN UNIVERSITY

(i) *Department of Agriculture*

Nutritional and husbandry studies of sheep.

(ii) *Department of Biological Chemistry*

(a) Metabolism of nitrifying bacteria.

(b) The breakdown of amino acids and other organic compounds in soils.

2. ABERYSTWYTH, UNIVERSITY COLLEGE OF WALES

Institute of Rural Science

The variations in the moisture content of cut herbage material under varying conditions of temperature and humidity.

3. BANGOR, UNIVERSITY COLLEGE OF NORTH WALES

(i) *Department of Agricultural Botany*

Mineral nutrition of certain races of wild white clover.

(ii) *Department of Agricultural Chemistry*

(a) Bracken poisoning.

(b) Biochemical and nutritive properties of pasture.

(c) The metabolism of herbicides by soil bacteria.

4. BIRMINGHAM UNIVERSITY

(i) *Department of Anatomy*

(a) Presumed nervous control of anterior pituitary gland.

(b) Cyclical changes in the male accessory organs of the hedgehog.

(ii) *Department of Botany*

(a) Inheritance of frost resistance in the potato.

(b) Expedition to Mexico and Central America to collect wild *Solanum* material.

5. BRISTOL UNIVERSITY

(i) *Department of Animal Husbandry*

Unidentified growth factors required of poultry.

(ii) *Department of Physiology*

(a) Bovine acetonaemia.

(b) Effect of oestrogen on the adrenal cortex.

(iii) *Department of Veterinary Anatomy*

Problems of avian respiration.

6. CAMBRIDGE UNIVERSITY

(i) *School of Agriculture*

(a) Carcass quality of beef.

(b) Resistance of *Solanum andigenum* to potato root eelworm.

(ii) *Department of Animal Pathology*

Respiratory diseases in poultry.

- (iii) *Department of Biochemistry*
Biochemistry of the uterus.
- (iv) *School of Botany*
 - (a) Growth and form of an annual plant as a function of environmental conditions.
 - (b) Nature and origin of physiological races in *Phytophthora infestans*.
- (v) *Cavendish Laboratory*
Maintenance-operation of the Siemens Electron Microscope.
- (vi) *Department of Colloid Science*
Surface properties of cells.
- (vii) *Molteno Institute*
Comparative physiology of parasitic protozoa in helminths.
- (viii) *Department of Pathology*
 - (a) Immunology and serology. (A five-year block grant made jointly with the Nuffield Foundation.)
 - (b) Blood groups of the pig.
- (ix) *Department of Veterinary Clinical Studies*
 - (a) Neonatal mortality and haemolytic diseases among animals.
 - (b) Sow's mammary gland in health and disease.
 - (c) Action of ganglion blocking agents in animals under conditions of anaesthesia.

7. DURHAM UNIVERSITY (KING'S COLLEGE)

- (i) *School of Agriculture*
 - (a) Progeny testing of cattle for meat and milk production.
 - (b) Pig farrowing accommodation studies. (A long-term grant.)
- (ii) *Department of Chemistry*
Mechanism of melanin formation.
- (iii) *Department of Zoology*
Cytology of the genus *Heterodera*.

8. EDINBURGH UNIVERSITY

- (i) *Departments of Agriculture and Chemistry*
Grass Conservation. (A five-year block grant.)
- (ii) *Department of Animal Genetics*
 - (a) Genetics of beef and milk production in dual purpose cattle.
 - (b) Fertilisation and early embryonic development in animals.
- (iii) *Department of Zoology*
Insect cell culture.

9. GLASGOW UNIVERSITY

- (i) *Department of Botany*
An analysis of the effects of dalapon and amino triazole on bracken.
- (ii) *Department of Veterinary Medicine*
 - (a) John's disease.
 - (b) Relationship of the feeding and management of sows to the health and survival rate of litters.
 - (c) Pathology of pneumonia in pigs.
 - (d) Plasma, respiratory and venal responses to experimental shifts in acid base balance of metabolic origin.
 - (e) Bacteriological research.
 - (f) Immunological studies in young domestic animals.
- (iii) *Department of Zoology*
Midgut, peritrophic membrane and the enteric casca in Diptera (Cyclorrhapha).

10. HARPER ADAMS AGRICULTURAL COLLEGE

- (a) Poultry husbandry investigations.
- (b) Pig husbandry investigations.

11. LEEDS UNIVERSITY

- (i) *Department of Agriculture*
Nutrition of the pregnant sow.
- (ii) *Department of Biochemistry*
A study of the enzyme systems in insects responsible for the *in vivo* activation of organo-phosphorus insecticides into anti-cholinesterases.
- (iii) *Department of Botany*
Structure of cell walls of apple fruit and "rubbery wood" of apple trees (in collaboration with East Malling Research Station).
- (iv) *Dental School and Hospital*
Effects of fluorine in bone metabolism.

12. LIVERPOOL UNIVERSITY

- (i) *Department of Biochemistry*
Biosynthesis of riboflavin.
- (ii) *Department of Veterinary Anatomy*
Nervous and vascular mechanisms involved in semen production.
- (iii) *Department of Veterinary Preventive Medicine*
 - (a) Coccidiosis in turkeys.
 - (b) Respiratory diseases of poultry.
- (iv) *Department of Zoology*
Comparative endocrinology.

13. LONDON UNIVERSITY

BIRKBECK COLLEGE

- Department of Physics*
Molecular structure of viruses.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY

- (i) *Department of Botany*
Fat production by fungi in culture on artificial media.
- (ii) *Research Institute of Plant Physiology*
Bulbing of onions.
- (iii) *Departments of Zoology and applied Entomology*
Insect ecology.
- (iv) *Departments of Zoology and applied Entomology, and Botany*
Action of fumigants on seed-borne fungi.

KING'S COLLEGE

- Department of Botany*
 - (a) Research on the physiology of growth hormones.
 - (b) The metabolism of certain newer amino and imino acids by soil micro-organisms.

LISTER INSTITUTE OF PREVENTIVE MEDICINE

- (a) Mechanism of starch-carbohydase action.
- (b) Research on protozoa.

LONDON HOSPITAL MEDICAL SCHOOL

- Department of Biochemistry*
Study of electrophoretically distinct haemoglobins in the blood of sheep.

ROYAL VETERINARY COLLEGE

- (a) Calf diseases (joint investigation with National Institute for Research in Dairying).
- (b) Extrachromosomal influences in development and heredity.
- (c) Relation between climatic environment and productivity in poultry.
- (d) Gustatory senses in cattle.

UNIVERSITY COLLEGE

- (i) *Department of Anatomy*
Perfusion *in vitro* of the pregnant uterus.
- (ii) *Department of Biochemistry*
Biochemistry of lactation.
- (iii) *Department of Zoology*
 - (a) The phenomena of acquired tolerance of tissue grafts.
 - (b) Cytological effect of inbreeding in *Drosophila*.

WYE COLLEGE

Poultry breeding. (A long-term grant.)

14. LONG ASHTON RESEARCH STATION
Blackcurrant gall mite.

15. MANCHESTER UNIVERSITY
Department of Botany
Cytogenetical investigations on soft fruits. (A five-year block grant.)

16. NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING
Farm Buildings Research.

17. NATIONAL VEGETABLE RESEARCH STATION
The effect of sub-lethal doses of herbicides on vegetable crops.

18. NORTHERN POULTRY BREEDING STATION
Poultry research.

19. NORTH OF SCOTLAND COLLEGE OF AGRICULTURE
Control of gangrene, blackleg and soft rot in potatoes.

20. NOTTINGHAM UNIVERSITY
(i) *Department of Agriculture* (in collaboration with A.R.C. Unit of Plant Cell Physiology)
Germination of *Orobanche*.

(ii) *Department of Horticulture*
Diagnosis of damage from spray drift.

21. OXFORD UNIVERSITY

- (i) *Department of Agriculture*
 - (a) Investigation into the uptake or absorption by plants, soils, and animals of radio isotopes.
 - (b) Mechanisms of peptide formation.

(ii) *Department of Biochemistry*
Fractionation and characterisation of β -lactoglobulin.

- (iii) *Department of Botany*
 - (a) Ability of plant nuclei to respire.
 - (b) The resistance of oats to certain diseases.

(iv) *Nuffield Institute for Medical Research*
Scrapie research.

- (v) *Department of Zoology*
 - (a) Comparative behaviour of weaver finches.
 - (b) Genetics of polyhedral virus disease in insects and studies of non-genetic determinants in inheritance.

22. READING UNIVERSITY

- (i) *Department of Agriculture*
Poultry husbandry investigation. (A long-term grant.)
- (ii) *Department of Agricultural Botany*
 - (a) Competition among plants of wet grassland.
 - (b) Physiological and ecological aspects of crop growth.
- (iii) *Department of Agricultural Chemistry*
 - (a) Study of the hen egg shell.
 - (b) Chemistry of bone changes associated with egg laying in the domestic fowl.
- (iv) *Department of Horticulture*
Growth development and floral morphology of carnations.
- (v) *Department of Microbiology*
 - (a) Nutrition and metabolism of pleuropneumonia-like organisms.
 - (b) Serology of streptococci.

23. ROTHAMSTED EXPERIMENTAL STATION

- (a) Rental and maintenance of electronic computer in the Statistical Department.
- (b) Insecticide investigations. (The money for this grant is provided by the Colonial Office.)
- (c) Nutrition of forest trees in nurseries. (The money for this grant is provided by the Forestry Commission.)
- (d) Pyrethrum Research. (The money for this grant is provided by the Colonial Office.)

24. ROWETT RESEARCH INSTITUTE

Absorption and elimination of natural and radioactive isotopes of calcium, strontium and barium in sheep.

25. UNIVERSITY COLLEGE OF SWANSEA

Department of Botany

- (a) Verticillium wilt of lucerne and brussels sprouts.
- (b) Studies on the organic and inorganic nutrients in *Eriophorum vaginatum* L.

26. OTHER ORGANISATIONS AND INDIVIDUALS

- (i) *Electrical Research Association*
 - (a) Crop conservation and storage.
 - (b) Farm machinery and equipment.
 - (c) Electricity in livestock husbandry.
 - (d) Electricity in horticulture.
 - (e) Other specialised application of electricity.
- (ii) *Private A.I. Centres Group*
Infertility in cattle.
- (iii) *The Polytechnic, London*
Biological control of eelworms by means of predacious fungi.
- (iv) *C. B. Williams, M.A., Sc.D., F.R.S.*
Relation of weather conditions to insect activity and insect population.

SOIL

ROTHAMSTED EXPERIMENTAL STATION

Harpenden, Herts.

Director: SIR WILLIAM G. OGG, M.A., B.Sc., LL.D., Ph.D., F.R.S.E.

Deputy Directors: A. Muir, Ph.D. (Soils Division)
F. C. Bawden, M.A., F.R.S. (Plant Pathology Division)

PHYSICS

Head of Department: H. L. Penman,
M.Sc., Ph.D., F.Inst.P.
G. H. Cashen, M.Sc.
J. L. Monteith, B.Sc., Ph.D., A.Inst.P.

CHEMISTRY

Head of Department: G. W. Cooke,
Ph.D., F.R.I.C.
P. W. Arnold, M.A., B.Sc., Ph.D.
Blanche Benizian, B.Sc.
J. M. Bremner, B.Sc., Ph.D.
J. K. R. Gasser, B.Sc., M.Sc., A.R.I.C.
Signe G. Heintze, M.Phil.
G. E. G. Mattingly, Ph.D.
H. A. Smith
O. Talibudeen, M.Sc., Ph.D.
R. G. Warren, B.Sc.

PEDOLOGY

Head of Department: A. Muir, Ph.D.
C. Bloomfield, Ph.D., F.R.I.C.
G. Brown, B.Sc.
R. Greene-Kelly, Ph.D.
I. Stephen, B.Sc., Ph.D.

TROPICAL SOILS ADVISER

H. Greene, D.Sc.

SOIL MICROBIOLOGY DEPARTMENT

Head of Department: P. S. Nutman,
Ph.D., A.R.C.S.
R. M. Jackson, B.Sc.
Mrs. Janina Kleczkowska, Ph.D.
Jane Meiklejohn, Ph.D.
F. A. Skinner, M.A., Ph.D.
N. Walker, Ph.D., F.R.I.C.

BOTANY

Head of Department: D. J. Watson, Ph.D.
E. C. Humphries, D.Sc.
Joan M. Thurston, B.Sc.

BIOCHEMISTRY

Head of Department: N. W. Pirie, M.A.,
F.R.S.
Margaret Holden, B.Sc.
R. H. Kenten, B.Sc.
P. J. G. Mann, B.Sc., Ph.D.
M. V. Tracey, M.A.

PLANT PATHOLOGY

Head of Department: F. C. Bawden,
M.A., F.R.S.
S. N. Adams, D.Phil.
L. Broadbent, D.Sc.
E. W. Buxton, Ph.D.
R. A. Dunning, M.Sc., Ph.D.
Mary D. Glynn, D.Sc.
J. M. Hirst, D.S.C., B.Sc., Ph.D.
R. Hill, Ph.D.
B. Kassanis, D.Sc.
A. Kleczkowski, M.D., Ph.D.
I. Macfarlane, B.Sc., Ph.D.
H. L. Nixon, M.A.
G. A. Salt, M.A., Ph.D.
Marion A. Watson, Ph.D.

NEMATODOLOGY

Head of Department: F. G. W. Jones, M.A.
C. C. Doncaster, B.Sc.
Mary T. Franklin, Ph.D.
J. B. Goodey, Ph.D.
J. J. Hesling, B.Sc., A.R.C.S.
H. R. Wallace, Ph.D.
R. D. Winslow, B.Agr., Ph.D.

INSECTICIDES AND FUNGICIDES

Head of Department: C. Potter,
D.Sc., D.I.C.
P. E. Burt, B.A.
M. Elliott Ph.D.
F. T. Last, Ph.D., D.I.C., A.R.C.S.
K. A. Lord, M.A., Ph.D., A.R.I.C.
A. H. McIntosh, B.Sc., Ph.D.
J. Ward, B.Sc.
M. J. Way, M.A.

ENTOMOLOGY

Head of Department: K. Mellanby,
C.B.E., Sc.D.
C. J. Banks, Ph.D.
H. F. Barnes, M.A., Ph.D.
R. M. Dobson, M.A., Ph.D.
C. G. Johnson, D.Sc.
D. B. Long, M.A., Ph.D.
P. W. Murphy, D.Phil., B.Agr.Sc.,
F. Raw, Ph.D.

BEE RESEARCH

Head of Department: C. G. Butler, Ph.D.
L. Bailey, M.A., Ph.D.
J. B. Free, M.A., Ph.D.
J. Simpson, M.A., Ph.D.

STATISTICS

Head of Department: F. Yates, sc.D.,

F.R.S.

D. A. Boyd, Ph.D.

B. M. Church, B.Sc.

J. H. A. Dunwoody, B.A.

M. J. R. Healy, B.A.

F. B. Leech, B.Agr., M.R.C.V.S.

S. Lipton, M.Sc.

H. D. Patterson, M.Sc.

D. H. Rees, B.Sc.

M. H. Westmacott, B.A.

FIELD EXPERIMENTS

Head of Section: H. V. Garner, O.B.E.,

M.A., B.Sc.

G. V. Dyke, M.A.

ROTHAMSTED AND WOBURN FARMS

Head of Farms: J. R. Moffatt,

B.S.(Agric.) N.D.A., A.I.B.A.E.

Secretary: J. B. Bennett, A.C.A. *Librarian:* D. H. Boalch, M.A.

On 31st March, 1958, the scientific and experimental staff of the Station numbered 161.

CURRENT WORK AND OUTCOME OF RESEARCH

Of the many lines of work described in the Annual Report of Rothamsted Experimental Station, the few mentioned here are mainly those with a direct bearing on agricultural practice.

Crops and Fertilizers

Contrary to general belief, deep ploughing and subsoiling had little effect on crop yields; on some soil types potato crops were slightly increased but they were decreased on others; at Rothamsted in a long-term rotation experiment, the only crop that yielded more with deep ploughing was sugar beet, and it increased by only 6 per cent.

Irrigation in the spring of 1957 greatly increased the yield of grass and of most arable crops—4 inches of water doubled the yield of beans—but from mid-July on rain was adequate for all crops.

The widespread practice of splitting the nitrogenous dressings for winter wheat gave no benefit, and applying all of it in spring gave the same yields as applying half at sowing and half in spring. Heavy dressings of calcium nitrate drilled with the seed damaged spring-sown cereals, whereas the same amount of nitrogen given as ammonium sulphate did not. Vegetables yielded no better with concentrated organic fertilizers than with ammonium sulphate, which is much cheaper. The maximum economic return from nitrogenous fertilizers in 1957 came from half the dressing needed in 1955. Ammonium salts were converted to nitrate, and nitrate washed out of the top soil, more slowly than previously thought; although leached during prolonged wet weather, it was not by average summer rainfall.

No alternative phosphatic fertilizer proved superior to superphosphate; dicalcium phosphate dihydrate gave as good yield responses with many crops on several types of soil, but it is a dusty powder difficult to handle.

Work with the nitrogen-fixing bacteria showed that the populations of the free-living *Azotobacter* vary from season to season and with both the cropping and manuring. Symbiotic nitrogen-fixers occur in all normal soils in the United Kingdom, but not all are equally effective in fixing nitrogen: all soils in which clover had been grown for more than one season contained viruses (bacteriophages) that attack the nodule bacteria, but the importance of these in determining the character of the bacterial population is uncertain.

Growth studies with crops showed that the main factor determining their yield is leaf area and that there is little scope for increasing yield by varying the rate of photosynthesis. As only the upper leaves are fully active when leaf area is maximum, increasing yields entails keeping the maximum leaf area for a

longer period than at present, rather than increasing it when it is already greatest.

The technique for extracting edible protein from leaves was improved to produce an almost tasteless product that can be given a range of flavours. The high nutritive value suggested from its amino acid constitution was confirmed by animal feeding tests.

Under temporary leys, the population of wild-oat seeds fell rapidly in the first two years, but then only slowly. Stubble burning stimulated the germination of wild-oat seeds at or near the surface of the soil, but most seeds were not affected.

Pests and Diseases

The mild winter and spring led to unusually early and heavy aphid infestations and virus diseases were consequently more prevalent than for several years. Cereal yellow dwarf, newly recognized here, caused considerable losses. The spread of potato leaf roll and sugar beet yellows was checked by spraying with suitable insecticides, but only when they were applied very early. Yields of sugar beet were increased by up to 4.5 tons per acre by timely sprayings with "Metasystox", but late applications gave no benefit. A single spraying of spring beans, by controlling the black aphid, increased yields from 4 to 28 cwt. per acre.

No spray was found that controlled wheat-bulb fly; drilling dieldrin with the seed was the most effective treatment, but was costly.

Studies of the weather favouring apple scab allowed outbreaks, and the consequent need to spray, to be more accurately forecast, and in the Wisbech area the disease was better controlled than previously, although sprayings were fewer.

The importance of previous crops in determining the health and yield of cereal crops, especially wheat, was clearly demonstrated; yields were highest after beans and potatoes.

A high proportion of field populations of the potato-root eelworm were found to contain forms that attack resistant potatoes bred by crossing cultivated varieties and wild potatoes from the Andes, and these forms multiply rapidly when such "resistant" potatoes are grown. *Solanum vernei*, however, proved resistant to all forms against which it was tested. Progress was made in isolating the factor exuded by potato and tomato roots that makes the eelworm cysts hatch.

Bees

Of various results important to bee-keepers, perhaps the most useful was the checking of bees drifting from colony to colony, which spreads disease and nullifies breeding programmes based on records of honey production, by arranging hives irregularly, painting them in different colours, and, most effective, facing them in different directions.

Statistics

The electronic computer allowed statistical work to be much increased and three times as many analyses were made as in 1956. In addition to work with Rothamsted experiments, surveys were made and data analysed for many research stations and other organisations.

THE MACAULAY INSTITUTE FOR SOIL RESEARCH

Craigiebuckler, Aberdeen

Director: D. N. McARTHUR, C.B.E., D.Sc., Ph.D., F.R.I.C., F.R.S.E.

Deputy Director: R. L. Mitchell, B.Sc., Ph.D., F.R.I.C., F.R.S.E.

PEDOLOGY

Head of Department: Vacant

R. C. Mackenzie, D.Sc., Ph.D., F.R.I.C.

B. D. Mitchell, B.Sc.

W. A. Mitchell, B.Sc.

R. A. Robertson, B.Sc.

and Officers of the Soil Survey (Scotland)

SPECTROCHEMISTRY

Head of Department: R. L. Mitchell,

B.Sc., Ph.D., F.R.I.C., F.R.S.E.

V. C. Farmer, B.Sc., Ph.D.

R. O. Scott, B.Sc., Ph.D., A.R.I.C., A.R.T.C.

D. J. SWAINE, M.Sc., Ph.D., F.R.A.C.I.

A. M. Ure, B.Sc., Ph.D.

BIOCHEMISTRY

Head of Department: J. S. D. Bacon,

M.A., Ph.D.

R. B. Duff, B.Sc., Ph.D.

R. I. Morrison, B.Sc., Ph.D., A.R.I.C.

PLANT PHYSIOLOGY

Head of Department: P. C. de Kock,
M.Sc., D.Phil.

W. M. Crooke, B.Sc., Ph.D.,

Dip.Ag.sci., A.R.I.C.

A. H. Knight, B.Sc., A.R.I.C.

SOIL FERTILITY

Head of Department: E. G. Williams,
B.Sc., Ph.D.

G. Anderson, B.Sc., Ph.D.

J. W. S. Reith, B.Sc.(Agr.), Ph.D., A.R.I.C.

MICROBIOLOGY

Officer in Charge: D. M. Webley,
M.Sc., Ph.D.

FOREST SOILS

Officer in Charge: T. W. Wright,
B.Sc.(For.), Ph.D.

STATISTICS

Officer in Charge: R. H. E. Inkson,
B.Sc., F.R.S.S.

Secretary: Miss E. J. Dey *Librarian:* Miss A. M. B. Geddes, M.A., F.L.A.

The Macaulay Institute for Soil Research was founded in 1930, following a review of the most appropriate methods of utilizing a benefaction of Dr. T. B. Macaulay of Montreal, who desired to do something to assist Scottish agriculture, particularly in the marginal areas. It had at 31st March, 1958, a staff of 146, including 67 scientific and experimental officers.

The Institute is concerned with the study of the soil and of the soil-plant relationship in all its aspects. It has developed a number of specialized facilities, such as its spectrochemical laboratory, which are available to other kindred institutes when required. The ultimate aim of the research programme is the maintenance and improvement of the fertility of the soils of Scotland, from the point of view of both the plant and the animal.

The mansion house and the post-war temporary buildings have become inadequate. Eventually laboratories, administration, library and workshops will all be housed in new premises, the first stage of which should be completed in 1960.

The director, Dr. D. N. McArthur, retired on 31st March, 1958, and has been succeeded by Dr. A. B. Stewart, formerly Professor of Agriculture in the University of Aberdeen.

CURRENT WORK

During the past year the department of Pedology has continued investigations on the study of clay minerals and on the mode of occurrence of nutrients in soils, employing differential thermal and X-ray diffraction techniques. Phosphate fixation in soils has been a subject of particular study, both in this and other departments. The Peat Ecology section has been associated with reclamation work in various areas in Scotland in addition to research projects on the nature and development of peat deposits. The work of the Soil Survey of Scotland, which is part of the department of Pedology, is discussed elsewhere.

The department of Spectrochemistry has specialized in the development of methods for the determination of trace elements in soils and plant materials. During the year a Rockefeller Foundation Grant has enabled a Hilger Direct Reading Attachment for the Medium Quartz Spectrograph to be installed. This makes possible the simultaneous determination of up to 11 elements without photographic recording, and is operating very satisfactorily. So far it has been employed on a routine scale for the determination of copper and other elements in soil extracts with greater convenience and accuracy than was previously possible. Trace element investigations in progress include a detailed study of their distribution in soils and, in collaboration with the department of Soil Fertility, a study of the relationship between soil content and plant uptake. Particular attention is paid to such biologically important elements as cobalt, copper, manganese, molybdenum and zinc.

The current work of the department of Biochemistry includes studies of the organic constituents of soils and peats, of the metabolic products of soil micro-organisms and of relevant aspects of plant biochemistry. Mention may be made of investigations on the structure of humic acids, on the synthesis of 6-O-acetylglucose by specific soil micro-organisms and on the occurrence of free amino acids in plants.

In the department of Plant Physiology work on inorganic plant nutrients has suggested a correlation between P:Fe and K:Ca ratios on the one hand and the amounts of amino and other organic acids present in the plant on the other. Studies on heavy metal toxicities in oat plants have continued, as has work on the uptake of ions by roots.

Investigations have been continued by the department of Soil Fertility on the significance of pedological factors and soil properties in relation to crop production and fertilizer practice. The first step is the characterization of the nutrient status and agricultural behaviour of different soil types, and of the fertilizer requirements of the main agricultural crops, by means of field and pot experiments. Several important influences of soil parent-material and drainage conditions have been found, and laboratory investigations on the nutrient status and other relevant properties of the soils have been continued to delineate the factors involved. Progress has been made in classifying soil inorganic phosphorus relationships and in studies on organic phosphorus, nitrogen and trace elements. Further investigations have also been carried out on the influence of factors such as form, method and time of application on the practical effectiveness of lime and fertilizers.

Work on actinomycetes and fungi has continued in the Microbiology section. The action of certain actinomycetes on hormonal herbicides has been shown to involve β -oxidation of the side chain. The detailed study of the microbiology of the root region has progressed and methods of assessing the phosphate released from insoluble phosphate minerals by soil micro-organisms have been investigated.

The Forest Soils section collaborates closely with the Forestry Commission in its long term studies of effects of inorganic fertilizers on conifers. The effect of tree growth on deep peat is being investigated.

The Statistics section, which is housed in the University Department of Statistics with the A.R.C. Unit of Statistics, evaluates results on behalf of most of the other Institute departments and plays a part in the planning of investigations.

A more detailed account of the work in progress can be obtained from the Annual Report.

SOIL SURVEY OF GREAT BRITAIN

England and Wales

Rothamsted Experimental Station, Harpenden, Herts.

Head of Survey: A. MUIR, B.Sc., Ph.D.

Deputy Head: D. A. Osmond, M.Sc., Ph.D., A.R.I.C.

G. D. Ashley, B.Sc.	R. A. Jarvis, B.Sc., F.R.C.S.
B. W. Avery, B.Sc.	J. W. King, B.Sc., A.R.I.C.
A. Crompton, B.Sc.	H. H. le Riche, B.Sc.
D. C. Findlay, B.A.	D. Mackney, B.Sc.
B. R. Hall, B.Sc.	R. S. Seale, M.A.
C. A. H. Hodge, B.Sc.	J. P. Watson, M.A.

Scotland

Macaulay Institute for Soil Research, Craigiebuckler, Aberdeen

Head of Survey: R. GLENTWORTH, B.S.A. (Manitoba), Ph.D.

J. W. Muir, B.Sc.(Agr.), A.R.I.C., N.D.A., N.D.D.

E. L. Birse, B.Sc.	J. C. C. Romans, B.Sc.
R. Grant, M.A., B.Sc.	J. M. Ragg, B.Sc.
D. Laing, B.Sc., A.R.I.C.	

During the year 1957, 848 sq. miles were mapped in Great Britain. Surveys were carried out in areas in the counties of Bedford, Glamorgan, Hertford, Somerset, York, Aberdeen, Ayr, East Lothian, Kincardine, Perth and Stirling; maps were in preparation for areas in the counties of Buckingham, Cambridge, Derby, Lancashire, Northumberland, Anglesey, Caernarvon, Flint, Aberdeen, Angus, Roxburgh and Stirling; memoirs were drafted for Denbigh, Rhyl, Berwick-on-Tweed and Kelso.

Special surveys included a detailed soil survey of the mosses of South West Lancashire and the preparation of soil maps for a proposed drainage scheme; surveys were made also in connection with the new motorways as certain engineering properties are related to major soil groups.

In conjunction with the Colonial Office, special surveys were carried out in Northern Rhodesia, Swaziland, Sierra Leone, British Guiana, Malta, Hong Kong. Surveys were also carried out in Iraq.

Soil maps and explanatory memoirs to accompany them are published and an Annual Report is issued by the Soil Survey Research Board.

On the 31st March, 1958, the number of scientific and experimental staff was 23 in England and Wales and 14 in Scotland.

A.R.C. UNIT OF SOIL PHYSICS

School of Agriculture, University of Cambridge

Director: E. C. CHILDS, Sc.D., Ph.D.

Senior Scientific Officer: A. N. Ede, M.A., M.Sc.

This Unit was established in 1951 to continue and extend studies in the Cambridge University School of Agriculture relevant to land drainage. The programme of research aims at elucidating those soil problems of a physical kind in which the water content is a factor. Such a programme includes not only studies in which the soil-water relationship is of primary interest, but also those in which the soil-water relationship provides a tool for the study of other important soil properties, such as the stability of soil aggregation which has proved of use when applied recently in a study of the restoration of open-cast coal sites.

On 31st March, 1958 the scientific and experimental staff of the unit numbered three.

CURRENT WORK

The mathematical theory of drainage has hitherto been developed by the hodograph analysis, in which the effect of the presence of a capillary fringe above the water table has been ignored, and no account has been taken of the presence of impermeable layers at depth. During the year an exact solution has been developed for the capillary fringe case, and an approximate one for the impermeable bed case. The former is in course of publication, but the latter remains to be explored in due course with the aid of a digital computer.

Experimental work in the sand tank has provided information on (a) the dependence of water table height on the depth of impermeable bed, (b) the effect of third dimensional variation, particularly that provided by the fact that a drain line is not continuously permeable but is a series of relatively impermeable pipes separated by gaps and (c) third dimensional variation provided by drain layout, as when minor drains intersect major in such a way that the separation of the latter is not *very* large compared with the separation of the former. This problem arises from the increasingly recommended use of moleculum-tile schemes for the less sound clay soils, and from a consideration of the application of newly developed machines for laying porous concrete drain tubes cheaply.

Field work is being undertaken on an increased scale, the object being to test the conclusions arrived at on a basis of theory and laboratory experiment by observations of suitable conventional drainage systems in the field. Instrumentation has been developed in this connection.

Some progress has been made and reported in the scientific press on the theory of the redistribution of water during the moisture profile development subsequent to irrigation.

During the year members of the Unit staff have collaborated with the N.A.A.S. in studies of sites where there are problems of restoration after the operation of open-cast coal winning.

PLANT BREEDING

PLANT BREEDING INSTITUTE

Maris Lane, Trumpington, Cambridge

Director: G. D. H. BELL, B.Sc., Ph.D.

CEREALS (WHEAT, BARLEY, OATS)

G. D. H. Bell, B.Sc., Ph.D.

F. G. H. Lupton, M.A.

R. N. H. Whitehouse, M.A.

LEGUMINOUS FORAGE CROPS

AND GRASSES

J. L. Fyfe, M.Sc.

H. H. Rogers, B.Sc.

PATHOLOGY

R. C. F. Macer, Ph.D.

BIOCHEMISTRY

A. R. H. Trim, B.A., Ph.D.

POTATOES AND BRASSICAS

H. W. Howard, M.A., Ph.D.

SUGAR BEET

G. K. G. Campbell, B.Sc., A.I.C.T.A.

CYTOGENETICS

R. Riley, B.Sc., Ph.D.

Secretary: F. B. Hatfield, B.Sc., D.P.A.

The object of the Institute is to engage in research on plant breeding for the improvement of the major crops of the country, but with special reference to the agriculture of the intensively farmed and drier areas of England. This

research is partly of a pure and partly of an applied nature. It includes the breeding of crop varieties for better yield and quality: the study of breeding methods and techniques including genetical and cytological analysis: the synthesis of disease and pest-resistant forms: and the application of biochemical, physiological and statistical knowledge and methods to special problems.

On 31st March, 1958, the scientific and experimental staff of the Institute numbered nineteen.

CURRENT WORK

The cultivation of cereals—wheat, barley and oats—continues to be the most important part of arable farming over most of the eastern parts of England, and in particular wheat and barley are being maintained at a very high level of production on a considerable acreage. The breeding work on wheat has been expanded during the last year in terms of the problems being dealt with, while the work on barley and oats has tended to be concentrated more on certain specific problems, although the emphasis in the winter wheat breeding has also been directed towards a few major objectives. In all three cereals an intensive study has continued on the improvement of breeding techniques with particular reference to hybridisation programmes and selection methods, and special field experiments were conducted to test the application of new ideas in statistics and biometrical genetics. This, combined with the use of more accurate methods of selection for disease resistance and grain quality in barley and in wheat, has led to a considerable increase in the complexity of the methods being used in handling the breeding material. On the other hand, special emphasis has also been laid on devising means for reducing the time necessary for the breeding of a new and improved variety in spite of the more detailed work required.

The intensive methods adopted for cereal production in this country demand ever higher yield potential in the varieties available to the grower, which must also be suitable for highly mechanised farming. Varieties have been selected for the attributes that determine satisfactory field behaviour, and also for those qualities required by the processor or consumer. With the higher standard expected in new varieties, and the more intensive systems of cropping, more emphasis is now falling on the importance of resistance to diseases and pests, in cereals as well as in other major crops such as potatoes and sugar beet. More time and effort have therefore been spent on trying to achieve a greater capacity on the part of the plant to withstand these depredations. As a consequence of this work two new winter wheat hybrids showing a high degree of resistance to yellow rust, and two new hybrids of spring barley with apparent immunity to mildew, have been sent forward for extensive field trials by the National Institute of Agricultural Botany.

Barley growers require, in addition to mildew resistance, two new developments for the more efficient production of good malting samples. In the first place there is a strong demand for an earlier ripening spring variety, and to meet this need five new hybrids were sent for national trials in 1958. Secondly, an improved winter-hardy malting variety is needed to replace the variety Pioneer which has been on the market for 12 years, and although three Institute selections have been in field trials for two years, more recent hybrids are proving superior and work has been continued on these during the past year.

The 1958 growing season has shown the seriousness of blight to the potato crop. The breeding work for resistance to this disease has continued, with two new clones being sent for national trials. Efforts to breed a potato variety resistant to root eelworm have been expanded during the last year as new glasshouse facilities have become available. Satisfactory progress was made, by hybridisation involving two or three backcrosses, in obtaining promising

clones resistant to the form of eelworm being currently used in testing. Unfortunately a new form of the eelworm has been found to which these clones are susceptible, and it will now be necessary to try to incorporate, by separate hybridisation, resistance to this new form.

Among the many problems involved in breeding for improvements in sugar beet, the reduction in the losses caused by infection by virus yellow disease is one of the most important. It is now known that there are various strains of the virus causing sugar beet yellows, and that there are genetic differences in sugar beet causing differences in tolerance to at least one of the strains. For testing tolerance to this severe strain a glasshouse technique has been developed, and, although subsequent testing to other strains will be necessary, progress has been made in isolating promising tolerant sugar beet lines.

The work on certain leguminous, forage and herbage crops has shown some interesting developments. In winter beans attempts are being made to exploit hybrid vigour by the use of male sterility, while selection is being practised in this crop to improve such characters as winter hardiness. Intensive selection in marrow stem kale has resulted in the isolation, by inbreeding, of special purpose types with improved edibility, leaf retention and winter hardiness, while genetic studies have shown how it should be possible to synthesise double crosses for commercial utilisation. Several grass species, including timothy, cocksfoot and tall fescue, have been subjected to selection for new types suitable for the more extreme ecological conditions and for extended seasonal production, while a special study has been made of selection methods in these herbage plants.

Considerable developments have been made in the cytogenetic work in the *Triticinae* where more refined methods have been used in the exploitation of wide crossing in this group of plants. Chromosome substitution and addition lines have been established in wheat-rye hybrids, while certain amphiploids have been used for hybridisation with wheat.

The fundamental research in biochemistry has continued principally in the study of plant nucleic acids, and considerable improvements have been made in the methods of isolation of these substances. The biochemical work has also made valuable contributions to the study of the virus causing sugar beet yellows.

WELSH PLANT BREEDING STATION

Plas Gogerddan, Nr. Aberystwyth

Director: Professor E. T. Jones, M.Sc., N.D.A., N.D.D.

Deputy Director: Gwilym Evans, M.Sc.

GRASS BREEDING

Head of Department: A. R. Beddows,

M.Sc., F.L.S.

Martin Borrill, B.Sc., Ph.D.

PLANT GENETICS (GRASSES)

Head of Department: J. P. Cooper,

B.Sc., Ph.D.

CLOVER BREEDING

Head of Department: W. Ellis Davies, B.Sc.

A. J. H. Carr, B.Sc., Ph.D.

CEREAL BREEDING

Head of Department: D. J. Griffiths,

M.Sc., Ph.D.

GRASSLAND AGRONOMY

Head of Department: Ll. Iorwerth Jones,

B.Sc.

W. E. J. Milton, M.Sc., N.D.A.

D. G. Miles, B.Sc.

SEED MULTIPLICATION

Head of Department: H. M. Roberts, B.Sc.

CYTOLOGY

Head of Department: Keith Jones,

B.Sc., Ph.D.

CHEMISTRY

Head of Department: G. ap Griffith,

B.Sc., Ph.D.

ASSISTANT TO DIRECTOR FOR FIELD EXPERIMENTS

Ll. Phillips, B.Sc.

Secretary: J. O. Parry-Williams, M.B.E.

The Welsh Plant Breeding Station, established in 1919, occupied new headquarters and breeding grounds at Gogerddan in 1954. Its main objectives include the breeding and development of improved strains and varieties of grasses, clovers and oats, together with the study of their agronomic behaviour and agricultural value. During the past few years the breeding of improved varieties of field beans, especially in respect of yields and earliness of ripening and of fodder *Brassica* species for hardness and leafiness, has been brought within the scope of the Station's work.

On the 31st March, 1958 the scientific and experimental staff of the Station numbered forty-two.

CURRENT WORK

Renewed attention is now given to the economic possibilities of inter-generic and inter-specific crosses of grasses and clovers. Encouraging results have been achieved in the restoration of fertility in sterile hybrids of *Lolium multiflorum* x *Festuca arundinacea* after doubling the chromosome number; it is hoped that purposeful selections may be made from the hybrid derivatives of these two genera. The development of strains to provide green growth during the winter period is one of the main objectives of the grass breeding activities; several strains bred for this purpose are now in field trials. In exploring further possibilities several ecotypes of *Dactylis* from the Mediterranean area, including diploids, have been found to be exceptionally winter green and have desirable foliar characteristics. Triploid hybrids of *Dactylis* have proved to be male sterile but partially female fertile when crossed with diploid and tetraploid forms. Cytological studies have shown that when back-crossed with the diploids the progenies were mostly diploid, and mostly tetraploid when back-crossed to the tetraploid; their fertility encourages the hope that new combinations of diploid and tetraploid genomes can be established. Further progress has been made in developing techniques for uncovering genetic variations in *Lolium* and *Phleum* under controlled photoperiod and temperature and in the application of this rapid technique for strain identification. Population studies in *Lolium* show marked response to repeated selection for time of ear-emergence and indicate

the possibility of developing non-flowering strains which remain permanently vegetative within the region of their adaptation.

Studies are continued on assessment techniques for clover breeding materials. It is important to find that the ranking of white clover families grown as single plants agrees with the ranking in broadcast plots, but this result was not obtained for lucerne strains. Reduced fertility in induced polyploids has been restored to a greater degree in lucerne than in white or red clover.

The development of satisfactory techniques of grass strain evaluation still remains fundamentally important, for methods of assessment must be practicable as well as sound. From the results of current agronomic experiments, it emerges that the type of management applied has a profound influence on the performance of a strain under sward conditions and on its clover companion; it is thus clear that one assessment figure is not valid for expressing the value of a strain relative to another when tested under different conditions. In the search for grasses to extend the grazing season two bred strains of perennial ryegrass are in trials; their distinctive growth rhythms have given encouraging contributions to the grazing in autumn, winter and early spring. The new cocksfoot under trial makes active growth in spring when the ordinary Danish variety remains virtually dormant.

By improving the techniques of seed production of bred herbage strains it should be possible to produce certified seed at reduced cost and to replace ordinary varieties more rapidly. The reduction of seed rates has had a markedly beneficial effect on seed yields, especially the fescues. Gibberellic acid has significantly stimulated earlier flowering and blossom production in S.123 red clover.

The chemist gives invaluable service to the breeder and the agronomist; preliminary studies indicate that "normal acid" fibre content increased when grass plants were grown widely spaced and N.P.K. Ca manuring was applied.

The problem of introducing disease resistance into cultivated oats is receiving increasing attention at the Station. For this purpose amphidiploids (6x) from derivatives of tetraploid and diploid crosses and inter-varietal hybrids are being explored. The possibility of obtaining agronomically useful mutants by X-ray treatment is also receiving attention. In these experiments interesting *fatua*-like mutants have been obtained by treatment of *Avena sterilis maxima*. Mildew in oats causes wide-scale loss in grain production and straw value; a new oat bred for resistance to mildew has given substantially better yields than Sun II in seasons when the incidence of mildew has been high. A new variety of winter oats, Penrhyn (S.234), has shown outstandingly superior grain production in official trials and has been recommended by the National Institute of Agricultural Botany with a view to distribution in the autumn of 1958.

Although the studies of *Vicia faba* show that this species is typically out-breeding, the evidence obtained indicates that long-term improvement may be sought in the development of superior self-fertile lines.

SCOTTISH PLANT BREEDING STATION

Pentlandfield, Roslin, Midlothian

Director: J. W. Gregor, D.Sc., Ph.D., Dip.Ag., F.R.S.E.

CEREALS

D. Cameron, B.Sc.

VIRUS DISEASES OF POTATO

G. Cockerham, B.Sc., Ph.D.

HERBAGE PLANTS AND GENECOLOGY

Patricia J. Watson, M.A., Ph.D., C.D.H.

POTATO BREEDING

W. Black, D.Sc., Ph.D., F.R.S.E.

ROOT CROPS AND SUGAR BEET

V. E. McM. Davey, B.Sc., Ph.D.

Secretary: R. J. L. Gallie

The aims of the Station are: (a) to conduct investigations calculated to yield information of scientific interest and especially information bearing upon the general problems of crop improvement; and (b) to produce new and improved varieties of direct value to agriculture.

On 31st March, 1958, the scientific and experimental staff of the Station numbered seventeen.

CURRENT WORK

Cereals. The study of resistance of oat varieties to stem eelworm has been continued and expanded. A laboratory test involving the injection of a suspension of eelworm into seedlings has been employed to assess varietal reaction to the presence of eelworm in the tissues, and four distinct types of reaction were detected—(1) where neither stunting nor basal dilation occurred; (2) where there was dilation but no stunting; (3) where there was stunting but no dilation; and (4) where both stunting and dilation were in evidence. The species *Avena ludoviciana* belongs to the first of these categories, the cultivars Early Miller and Albyn Empress to the second while the cultivar Milford is typical of the third, and susceptible cultivars such as Sun II to the fourth.

Herbage Plants and Genecology. A subject of particular interest in Scotland, and important also in England and Wales, is the improvement of hill pastures. This presents a complex of various problems, some of which this Station among others has a part to play in solving. More information is certainly required about the many different plant communities which form our hill grazings, and in particular about methods of adjusting the complementary usefulness of these communities.

From a consideration of the age of genotypes in these natural communities there is evidence that selection has not had the opportunity to differentiate populations on such a scale as has been shown to occur in certain other plant groups studied. Some of the clones recorded must be hundreds of years old to cover such an acreage, and so far as these particular genotypes are concerned, the populations may be regarded as relatively static. In terms of generations there has not been time for selective differentiation to become obvious, except under very drastic selection pressures. These genecological studies provide a logical approach to the problem of finding material suitable for any breeding programme that may ultimately be initiated.

During recent years the Station has been associated with developments which aim at facilitating the international exchange of herbage cultivars.

Potatoes. The primary objective is to breed varieties resistant to disease, particularly to blight, root eelworm, and viruses A, Y, X, S and leaf-roll. In view of the widespread occurrence of virus S in commercial stocks work on this virus has been expanded, particular attention being paid to the effects on a number of potato varieties of both the paracrinkle strain from King Edward and the Station's stock strain from Arran Victory. A further collection of

South American potato material was examined for resistance to virus S but none was found.

Root crops. Several lines of investigation are being carried out with the leaf-bearing forms of *Brassica*, chiefly in the cabbage tribe, but also among the rape-like forms of Swede. For certain purposes, such as grazing of close spaced plants, the leafage of the marrow stem kale may be of more value than the stem. An attempt to combine heavy leafage with a short stem was started in 1951 when plants of a short-stemmed strain were crossed with selections from a strain known as New Zealand "Hybrid" kale, which had a large amount of foliage persisting into the winter, but which had stems as long as or even longer than normal marrow stem. Last year derivatives of these crosses were compared with marrow stem under conditions of thin sowing and no singling.

In 1957, third generation progenies of selected plants of broccoli $\times$ thousand-headed kale became available. Two main groups of broccoli hybrids were represented, one descended from Royal Oak, an April-heading type, and the other from Veitch's Self-Protecting broccoli which heads in autumn and is noted for its large leaves.

Crosses have also been made between thousand-headed kale and marrow stem kale, and between thousand-headed kale and spring cabbage.

A fuller description of the work is given in the Station's Annual Report.

A.R.C. UNIT OF BIOMETRICAL GENETICS

Department of Genetics, University of Birmingham, Edgbaston, Birmingham

Honorary Director: Professor K. Mather, C.B.E., D.Sc., Ph.D., F.R.S.
(Professor of Genetics, Birmingham University)

Honorary and Senior Scientific Staff:

C. J. Hickman, M.Sc., Ph.D. } (*Honorary Members*)
H. Rees, D.F.C., B.Sc., Ph.D. }
J. L. Jinks, B.Sc., Ph.D.
E. L. Breese, B.Sc., Ph.D.

The Unit was formed on 1st October, 1950. It is attached to the Department of Genetics in the University of Birmingham and the Professor of Genetics is the Honorary Director of the Unit. On 31st March, 1958, the scientific and experimental staff numbered five.

CURRENT WORK

In the study of continuous variation, which is one of the chief interests of the Unit, attention has been largely devoted to the application of the genetical principles already developed to the fuller analysis and understanding of results obtained from field experiments. When represented in the biometrical way necessitated by the impossibility of following individual genes in the mediation of continuous variation, genetical phenomena which have very different consequences for the plant breeder are not always readily separable in their immediately observable effects. This is especially true of the linkage springing from genes being carried on the same chromosome and the interaction which they may display in their control of the life processes of the plant. Tests are being devised for the separation of these two phenomena, and are being applied to data from experiment. A more general treatment of the two in combination is also under development. As would be expected, this new approach is revealing deficiencies in the experimental techniques of the past. It has been found, for example, that the mere germination of seeds and growth for a week of the seedlings in the same seed-pan can have effects persisting to the adult stage, which though

small in themselves may lead to difficulties in measuring the genetical components of the variation these adult plants show. Obviously, future experiments must be designed so as to take such complications into account.

Study of barley plants treated by irradiation has shown that this can and does add to continuous variation by mutation, just as it produces the more familiar gene changes of drastic effect. And in the same way, too, there are some indications that the mutations give results preponderantly in the direction away from the characteristics for which the breeder has selected in the past. Radiations may therefore be a tool of prospective value to the breeder in the control of continuous variation, but one which cannot be used indiscriminately and indeed one whose value has yet to be adequately assessed.

In higher plants and animals the cytoplasm appears to have little importance in heredity, the genetic determinants being virtually confined to the chromosomes of the nucleus. In the fungi, however, we see a different picture: the cytoplasm has been shown to carry gene-like entities upon which, in their collaboration with the nucleus, the adaptation and general well-being of the fungus in no small measure depends. Though studied in harmless fungi in the laboratory, evidence has accrued that these gene-like entities are prospectively just as important to disease-causing fungi in the wild. Nor is the genetic make up of the cytoplasm simple: there are at least two and very likely many more systems of genetic importance in the cytoplasm of the fungus which has been most studied. Furthermore the process of sexual reproduction appears to bear a special relation to the genetic system of the cytoplasm (as it does in a different way to the genes of the nucleus) for it appears to have the property of regulating or re-standardising the genetic content of the cytoplasm no matter how much this has altered during the vegetative growth of the fungus. How this important effect is brought about, however, is a question which only extensive further investigation can answer.

PLANT PHYSIOLOGY

RESEARCH INSTITUTE OF PLANT PHYSIOLOGY

Imperial College of Science and Technology

Prince Consort Road, South Kensington, London, S.W.7

Director: Professor F. G. Gregory, D.Sc., A.R.C.S., D.I.C., F.R.S.

NUTRITION

(Major element deficiencies)

F. J. Richards, D.Sc., F.R.S.

VERNALISATION OF CEREALS

Miss O. N. Purvis, D.Sc., Ph.D.

STOCK SCION RELATION IN THE
APPLE (Growth analysis of vigorous and
dwarfing stocks)

B. D. Bolas, D.Sc., D.I.C.

NUTRITION (Enzymology)

Mrs. H. K. Porter, D.Sc., F.R.S.

ROOT STOCK PROPAGATION

E. S. J. Hatcher, Ph.D.

PHOTOPERIODISM

W. W. Schwabe, B.Sc., Ph.D., A.R.C.S.

AUXIN STUDIES

C. L. Mer, Ph.D., A.R.C.S.

SPRAY DAMAGE OF FRUIT TREES

F. W. M. Llewellyn, B.Sc., A.R.C.S.

C. R. Hancock, B.Sc.

Researches in progress concern various aspects of growth and metabolism of plants covering morphogenic problems, carbohydrate metabolism, nutrition, stock/scion relations in fruit trees, vegetative propagation and growth hormones.

On 31st March, 1958, the scientific and experimental staff of the Institute numbered seventeen.

Morphogenic studies and the factors affecting flowering

The inhibitory effect of intercalated long days in a series of short day exposures previously recorded in *Kalanchoe Blossfeldiana* have been shown to hold for two other short day plants. The application of synthetic hormones indole-acetic acid, triiodobenzonic acid, and gibberellic acid has little effect on vernalization and devernalization in the *Chrysanthemum*.

An investigation on the dormancy of the liverwort *Lunularia cruciata* from Israel has revealed that the onset and breaking of dormancy is day-length controlled, and a quantitative study of these effects is in progress.

A detailed study of the effects of very long days (17–24 hrs.) on the flower initiation and ear development in winter rye with and without previous vernalization has been carried out. The separate effects in the photoperiodic cycle of the length of the dark period, of duration of high intensity and low intensity light respectively have been assessed. The preponderant effect of periods of high intensity light has been established, and also the greater promoting effect on flowering by a period of high light of given duration interrupted by a period of darkness has been shown. The complex interaction effects of daylength and duration of vernalization on flower initiation, ear growth and stem elongation have been successfully elucidated. An investigation of the responses of early and later varieties of wheat to vernalization and daylength is in progress. The work on the effects of age and nutrition on the morphology of the flax apex (phyllotaxy) has been extended to a study of factors determining the “divergence angle”: removal of the cotyledons in the seedling is found to have considerable and persistent effect.

Carbohydrate metabolism

The degradation of starch in the dark and the anaerobic synthesis of starch in the light have been studied in the leaf tissues of tobacco. The conclusion previously reached that the carbon dioxide evolved during degradation of starch in the dark derives directly from sucrose, which must therefore precede it in the chain of intermediate products, has been confirmed. When starch is synthesised in light from 14CO_2 and is then allowed to break down in the dark, the CO_2 of respiration has a specific activity of some 60 per cent of that supplied for assimilation. There is therefore considerable incorporation of carbon in leaf constituents other than starch during the cycle. A glucose polymer other than starch which becomes labelled during assimilation of 14CO_2 has now been isolated and is being characterised.

Anaerobic synthesis of starch from glucose has been achieved by infiltrating leaf tissues with glucose and exposure to light in the absence of both carbon dioxide and oxygen.

It has now been established fully that when cereal seedlings are supplied with hexose there is a symmetrical interchange of carbon atoms 1, 2 and 3 with atoms 4, 5 and 6, and a similar interchange has been demonstrated *in vitro* using barley root extracts.

Studies of the enzymes associated with sucrose synthesis in wheat scutella have continued, and the enzyme uridine diphosphokinase has now been isolated in crude form: this is as far as is known the first preparation of the enzyme from plant material.

Work has been begun on the translocation of carbohydrate in the tobacco by supplying a fully expanded leaf with 14CO_2 . After 1 or 2 hours radioactivity is found in specified leaves above the treated leaf but not in leaves below: translocation to the roots occurs but bypasses the leaves. Sucrose is the only translocate identified. Radioactive material not exported from the treated leaf appears to be very slowly lost and much persists until the leaf dies.

Nutrition

Work on amine metabolism has been continued. The main product of putrescine fed to clover now appears to be 8 amino butyric acid. A technique has been sought for the estimation of mono-, di- and tri-phosphate nucleotides in barley leaves, all the usual methods employed having failed. Sufficient progress has been made to warrant a preliminary investigation of the effects of potassium deficiency.

Stock/scion relations in the apple

The main interest in this investigation now centres upon methods of studying the rate of carbon assimilation of attached leaves of vigorous and dwarfing stocks. This has necessitated a thorough study of the effects of leaf shape, the shape and dimensions of the leaf chamber enclosing the leaves, the rate of air flow, and leaf temperatures at varying intensities of insolation. An adequate method is now in use.

Growth hormones

A long term study of the effects of conditions of storage of hardwood cuttings upon the rooting response to applied growth hormones and establishment in the field is proceeding.

The properties of the growth inhibitor extracted from the tissues of the plum are being further investigated, particularly the interaction with known growth promoters, and also the seasonal changes in inhibitor production.

The effects of short exposures to indole acetic acid on the subsequent extension growth of coleoptile segments have been studied, and also effects of high and low temperatures before exposure to auxin on subsequent growth.

A very full study of the distribution of growth among the organs of the etiolated oat seedling has been undertaken with the aim of elucidating the stimulating effect of CO₂ on the growth of the mesocotyl. Nutritive effects play a determining role and therefore analyses of carbohydrate distribution in relation to CO₂ supply are being undertaken.

A.R.C. UNIT OF PLANT CELL PHYSIOLOGY

Department of Agriculture, University of Oxford

Director: R. Brown, D.Sc., Ph.D., F.R.S.

Senior Scientific Officer: J. K. Heyes, M.Sc., Ph.D.

The work of the Unit is the study of growth and development at cell level. This includes investigations of the physiological characteristics of meristems, which are the regions in which cell division and cell expansion are most active.

During the year the significance of nucleic acids in cellular development was explored by further studies on the effects of 8-azaguanine on the growth of cultured roots. When the analog is added to the culture medium growth is depressed, but the inhibition is relieved when guanine is supplied. This immediately suggests an effect due to the replacement of guanine and it was shown with inhibited roots that ten per cent of the guanine in RNA is replaced by 8-azaguanine. No significant incorporation was found into the DNA, and the effect on growth may therefore be attributed to a primary change in the composition of the RNA. Studies on the activities of four separate enzyme systems suggested that the mechanism of the inhibition involves a change in the catalytic properties of the protein synthesised in the presence of the abnormal nucleic acid. In each case when the enzyme activity for the whole root was expressed in

terms of unit protein this value was lower in the treated than it was in the control material.

Certain observations on the growth of leaves begun earlier were also continued. The growth of the leaf was analysed in two species in terms of cell division and cell expansion, the analysis being extended from the formation of the primordium to the attainment of the maximum leaf area. It was found that cell number continues to increase until just before the mature area is established. The average cell volume continues to increase throughout the development of the leaf. It is clear from these results that the development of the leaf is not characterised by distinctive and separate phases of cell division and cell expansion. Enlargement is due to both processes proceeding simultaneously throughout the period of development of the leaf.

An investigation of the growth of excised apices in culture yielded significant results on the conditions that promote the induction of primordia. This work is still not complete but the results so far assembled indicate that the induction of primordia does not depend on the same conditions as these which promote growth in organs after formation.

PASTURE GRASSLAND RESEARCH INSTITUTE

Hurley, near Maidenhead, Berkshire

Director: William Davies, D.Sc.

Deputy Director: T. E. Williams, B.Sc.

LEY AGRONOMY

Head of Department: T. E. Williams, B.Sc.

A. J. Heard, B.Sc., M.Sc.

W. Stiles, M.Sc.

ANIMAL AGRONOMY

Head of Department: F. E. Alder,

D.F.C., B.Sc., M.A.

C. R. W. Spedding, M.Sc., Ph.D.

J. C. Tayler, M.A., Dip.Ag.

HERBAGE AGRONOMY

Head of Department: J. O. Green, M.Sc.

D. W. Cowling, B.Sc.

BIOCHEMISTRY AND ANIMAL NUTRITION

Head of Department: W. F. Raymond,

M.A., A.R.I.C.

J. M. A. Tilley, B.Sc., D.Phil.

Secretary: I. A. Owen Librarian: W. J. Baulkwill, B.A.

PLANT PHYSIOLOGY

Head of Department: R. H. M. Langer,

B.Sc., Ph.D.

R. D. Williams, B.Sc., Ph.D.

BIOMETRICS

Officer in Charge: C. D. Kemp,

B.Sc., Dip.Stat.

EXTRA-MURAL STUDIES

Officer in Charge: H. K. Baker

B.Sc., Ph.D., Dip.Ag.

MICROBIOLOGY

Officer in Charge: Miss E. Grossbard,

Ph.D., D.I.C.

Field work is concentrated on the composition, treatment and use of grassland swards, with special attention to extending the grazing season. While much of the work is agronomic, the team of scientists at the Institute includes workers in several other disciplines. The research activities are now allocated to five main departments and three smaller sections.

On 31st March, 1958, the scientific and experimental staff of the Institute numbered forty-nine.

CURRENT WORK

Herbage Agronomy is concerned with the primary examination of new materials and techniques, and with studying the management of swards and the yield and

quality of herbage harvested at all seasons of the year. Information is accumulating about ways and means of extending the grazing season and improving the yield and quality of winter grass. Some contribution is made by species or strains of herbage grasses showing a capacity to grow at low temperatures and low light intensities, and several of these are under study. Other aspects of the provision and use of winter grass include manuring and autumn and spring management in relation to periods of rest.

An intensive study is being made of the part played by white clover and other legumes in pasture production, and of their interaction with applied nitrogen.

Experiments with seeds mixtures are indicating that better results can be got with seed rates much lower than those currently used in agricultural practice. With regard to seed yields, also, evidence is being built up that shows possibilities of substantial increases.

Animal Agronomy measures grassland production in terms of animal products, using beef cattle and sheep. There is also some work on poultry, though work with pigs is in abeyance.

Further comparisons of calf-rearing methods have been made and have again shown that outdoor rearing can be successfully achieved, and a post-weaning grazing trial has re-emphasized the importance of rotational grazing on relatively clean land for the avoidance of husk.

Studies of beef cattle at later stages have included measurement of the summer production of lucerne and cocksfoot leys in terms of live weight gains, and the extension of autumn grazing for fattening cattle by using nitrogenous fertilizer in conjunction with different methods of sowing and managing lucerne and cocksfoot. Fill and carcass changes in cattle turned on to spring grass have also been further investigated.

A sheep production trial has been started to compare "commercial" and "S" varieties of perennial ryegrass and cocksfoot sown with and without white clover. The long-term work on factors affecting growth and reproduction of ewes and lambs at pasture continues.

Ley Agronomy investigates the influence of grass swards on the yields of subsequent arable crops in the rotation. Many experiments are necessarily long-term, and are building up gradually a picture of the effects of various leys and their management on soil conditions. They indicate that the nitrogen economy of the ley has the most marked influence on subsequent arable crop yields, and thus that the differential effects of grass species are much less marked than the effects of legumes in the ley. Correlations have been demonstrated between the amount of nitrogen mineralized on incubation of soils from under leys and the yield of the following cereal crop. Under the most intensive forms of grazing management on three-year leys, the availability of nitrogen to a following wheat crop was such that no yield responses were obtained to further nitrogenous fertilizer.

Work on grassland irrigation produced only limited information in 1957 because the rainfall was above normal.

Animal Nutrition and Biochemistry is concerned with methods of estimating pasture intake and with examining the digestibility of various herbages, in close association with Animal Agronomy. This department also does basic research into the chemistry of plant materials and provides an analytical service for the Institute as a whole.

The nutritive values of "first-cut" forages in the spring are being investigated, following suggestions from research in U.S.A. that these can be predicted from the date of cutting. While a general relationship exists, it appears that

species differ widely in their digestibility on a given date, ryegrass and clover being consistently more digestible than cocksfoot and lucerne. The herbage fed in these experiments were analysed for a wide range of constituents in the attempt to identify the chemical factors determining digestibility. Marked differences were found between cocksfoot and ryegrass in their contents of soluble sugars, hemicellulose and cellulose, which seem likely to be important.

Plant Physiology links up closely with *Herbage Agronomy* both in the field and in the laboratory. Studies of tiller growth and photoperiodism have particular bearing on the conditions influencing flowering and seed production, and consequently on practical problems of seed production in the field.

The smaller sections of *Microbiology* and *Biometrics* provide services for the whole Institute.

The *Extra-mural* section conducts experiments, in co-operation with the National Agricultural Advisory Service, under a wide range of conditions in different parts of the country, thus obtaining additional information within the Institute's research programme on winter grass production, the long term effects of manuring of leys and improvement of permanent pasture by use of herbicides. A part of its work is concerned with special problems associated with certain soil types, for example, the acid sands of the Bagshot series.

The annual report of the Institute is published as *Experiments in Progress* and gives a more detailed account of the range of projects that are under study.

HORTICULTURE, GLASSHOUSE CROPS AND FRUIT

JOHN INNES HORTICULTURAL INSTITUTION

Bayfordbury, Hertford, Herts.

Director: K. S. DODDS, D.Sc., Ph.D.

Senior Scientific Staff:

GENETICS

Head of Department: Vacant
P. R. Day, B.Sc., Ph.D.

PLANT BREEDING

Head of Department: Watkin Williams, M.Sc.
G. J. Dowrick, B.Sc., Ph.D.
G. M. Haskell, B.Sc., Ph.D.

PLANT CELL BIOLOGY

Head of Department: Vacant
L. E. La Cour, M.B.E.
J. McLeish, B.Sc., Ph.D.
N. Sunderland, B.Sc., Ph.D.

POTATO GENETICS

Head of Department: K. S. Dodds,
D.Sc., Ph.D.
J. B. Harborne, B.Sc., Ph.D.
R. K. McKee, M.A., Ph.D., A.I.C.T.A.

PHYSIOLOGY AND PLANT CULTURE

Head of Department: W. J. C. Lawrence,
O.B.E., V.M.H.
G. Hussey, Ph.D., A.R.C.S., D.I.C.
R. M. Whittle, B.Sc., Ph.D.

Secretary: G. R. Davies

The John Innes Horticultural Institution is concerned primarily with the investigation of the principles of inheritance in plants and their application in the improvement of agricultural and horticultural crops. A study is being made also of some physiological factors that control the growth and culture of plants. A report is published each year.

On 31st March, 1958, the scientific and experimental staff of the Institution numbered thirty-seven.

CURRENT WORK

Genetics. Recently the fungus, *Coprinus lagopus*, has been adopted as an organism for probing certain genetical problems, notably the structure of its two mating loci. About fifty auxotrophic mutants, each with a particular requirement for growth on minimal medium, have been isolated and 6 and 3 of these are closely linked with the A and B mating loci respectively. Having these neighbouring markers, it is now possible to contemplate experiments designed to measure recombination within the mating loci.

Plant Cell Biology. The incorporation of thymidine into the DNA of nuclei in roots of seedlings of *Vicia faba* and other plants is being studied. The labelled substance is incorporated into the chromosomes during DNA synthesis at interphase and its distribution in subsequent mitoses can be followed in autoradiographs by the film-stripping technique. The results are of interest concerning the mode of replication of chromosomes.

There is a need in cytology for methods which can be used in the microphotometric estimation of proteins or of individual amino-acids in cells. Preliminary experiments have indicated that the Sakaguchi colour reaction for arginine might be suitable for such application. It has been applied to the study of nuclei from root meristems and differentiated tissues of *Scilla campanulata*. Arginine values have been compared with DNA values obtained from measurements of the amount of Feulgen staining in the same material. Both sets of values fall into two classes corresponding with the telophase and prophase amounts of DNA.

Physiology and Plant Culture. The rates of formation and the subsequent development of leaves and flowers in the young tomato have been determined over a wide range of temperatures, light intensities, and day-lengths. The effect of early development on cropping is being worked out.

To further this and similar investigations, growth rooms have been designed by the Department having great flexibility and adaptability in operation with improved control of light, temperature and humidity. The first unit is in use and is itself a subject of experiments aimed at a comprehensive analysis of growth room climate and control.

Plant Breeding. Observations in the field during the past ten years on the occurrence of mildew (*Podosphaera leucotricha*) on several thousands of apple seedlings derived from crosses of thirty-one apple varieties have been analysed. Resistance is a quantitative character and no evidence of discontinuity between the progeny classes has been found. Of the cultivated varieties that were examined, Beauty of Bath and Lord Lambourne yielded highly resistant progenies. The varieties Kola, James Grieve, Dabinett and Annie Elizabeth gave progenies with average mildew resistance.

Work has continued on the role of the pollen parent in apomixis in *Rubus*. Using *R. laciniatus* as female parent in crosses with other polyploid species, it has been shown that there is generally an increase in seedling vigour with increases in the chromosome number of the male parent. As the seedlings are not sexual ones, it must be concluded that differences in the genetic constitution of endosperm are responsible for differences in vigour between progenies.

A new pear variety, Merton Pride, and a new cherry variety, Merton Reward, were released during the year. The pear is a cross between Glou Morceau and Williams' Bon Chrétien. It is a triploid that matures its fruit in mid-September. Merton Reward is a seedling from the cross Emperor Francis $\times$ Bedford Prolific: the fruit are black and ripen from mid to late July.

Potato Genetics. Examination of the flavonoid pigments of diploid potatoes and several colour mutants of various garden plants has revealed that a basic

pigment metabolism is common to a number of higher plants. Anthocyanidins and flavonols with the same hydroxylation pattern are frequently found to occur together in flower petals. While the anthocyanidins of *Solanum phureja* may be methylated, acylated and glucosidated in the 5-position, the related co-occurring flavonols are not. This suggests that these processes occur at a late stage in biosynthesis, if it is assumed that flavonols and the anthocyanidins arise from a common C₁₅ precursor. Other evidence suggests that single sugar residues are linked one at a time to the pigment molecules rather than that a preformed di- or trisaccharide is attached directly in one step.

In the practical work, much attention is being given to the selection of breeding lines resistant to virus Y from crosses between domestic varieties and certain wild species.

GLASSHOUSE CROPS RESEARCH INSTITUTE

Rustington, Littlehampton, Sussex

Director: F. W. Toovey, O.B.E., B.Sc., A.R.C.S., A.I.C.T.A.

PLANT PATHOLOGY

Head of Department: P. H. Williams,
B.Sc., M.I. Biol.

ENTOMOLOGY

Head of Department: N. W. Hussey,
B.Sc., Ph.D.

PLANT PHYSIOLOGY

Head of Department: E. R. Leonard,
D.Sc., A.R.C.S., M.I. Biol.
A. J. Cooper, B.Sc., Ph.D.
H. R. B. Hack, B.A.

Secretary: J. Bishop, A.C.I.S. *Librarian:* Miss G. Dunster, B.A.
Nursery Manager: J. M. Evans, N.D.H.

CHEMISTRY

Head of Department: G. W. Winsor,
B.Sc., Ph.D., A.R.I.C.
J. N. Davies, B.Sc., Ph.D.
P. B. Flegg, B.Sc., A.R.I.C.
J. H. L. Messing, B.Sc.

PLANT BREEDING

L. A. Darby, B.Sc.

CROP PROTECTION

Head of Department: W. H. Read,
M.Sc., F.R.I.C.

The Institute was established in 1953 to undertake research bearing on the cultivation of glasshouse crops and mushrooms, and of bulbs, flowers and shrubs grown in the open. It replaced the Experimental and Research Station at Cheshunt, which had been working on glasshouse crops since 1915. Work is at present confined to the glasshouse crops tomato, cucumber, lettuce and carnation, and to mushrooms, but the development of the Institute is being continued. Special experimental glasshouses for some of the research departments and new buildings for mushroom research were almost completed by the end of the year.

On 31st March, 1958, the scientific and experimental staff numbered twenty-six.

CURRENT WORK

Plant Physiology. The basic study of the growth of the tomato carried out over three years at Cheshunt and at the Institute has led to an investigation of more practical aspects of tomato cultivation, and in 1957 an experiment on the interaction of pruning and spacing was laid down. Pursuing the growth analysis work, a time of planting experiment was started to determine the direct effects and the interaction of plant age and time of year on the growth of the tomato. The study of factors of the glasshouse environment likely to influence growth, in particular soil moisture tension, was continued.

Chemistry. Work has been resumed on the basic nutritional requirements of the tomato, and attention is being directed to some of the problems of liquid feeding. The magnesium nutrition of the tomato is also being studied, particularly in relation to the correction of the commonly occurring magnesium deficiency by foliar sprays.

The investigation of the chemical composition of tomato fruit has been extended very considerably, and chromatographic methods are being developed. Composition in relation to commercial grades has been studied, and particular attention is being paid to the relation between fruit ripening disorders and the composition of the walls or the locular contents of the fruit at various stages in ripening. As a result of this work the major trends in the composition of tomato fruit during ripening are now clearly established.

Experiments with the cultivated mushroom have shed interesting light on the function of the casing layer in initiating fruiting and appear to indicate that nutrients in the casing may be utilized more efficiently for sporophore production than those in the compost. The results from other experiments in which salts were added to the casing may lead to a practical means of improving the quality of mushrooms by increasing their size.

Pathology, Entomology and Crop Protection. The study of certain mushroom disorders which have recently caused much concern to growers is complicated by the wide variety of symptoms occurring, and by confusion with the symptoms of other imperfectly understood diseases. Using diseased material obtained from various sources, experiments have been carried out in the laboratory and in the growing house. The most significant result from the cropping experiment was the low yields given by several of the spawns, although no marked deformities were observed in the mushrooms produced. In the laboratory marked differences were observed in the growth of mycelia of cultures prepared from diseased sources.

Considerable attention is being paid to mushroom pests, and knowledge of their biology is advancing rapidly. Preliminary work has been taken up on the physiology of the Glasshouse Red Spider Mite, and the Glasshouse White Fly and its parasite, *Encarsia formosa*, are also being investigated.

Work on the *Didymella* Stem Rot of tomato, on cucumber mildew and on carnation wilt diseases has been continued.

Investigations on the control of chrysanthemum mildew by means of fungicides, and the determination of residues of diazinon on cucumber, have been carried out by the Crop Protection Department.

Plant Breeding. Breeding work with the tomato aims at reducing the excessive vegetative vigour of F_1 hybrids, which has hitherto limited their acceptance by growers, by incorporating the compact habit of the "Baby Lea" variety. Attention is also being paid to fruit size, shape and colour with the object of improving fruit quality. The investigation of fruit colour has particular reference to fruit ripening disorders.

With cucumber, F_1 hybrids are also being studied in the hope of improving yield and fruit quality and of obtaining a more uniform crop and more constant production. The work on lettuce is confined to winter-forcing varieties and aims principally at producing a variety which will heart as well as existing varieties, but which has a lighter green colour. For this, material raised from seed exposed to atomic radiation is being examined for mutations in leaf colour.

Detailed information about the work of the Institute is published in its Annual Report.

EAST MALLING RESEARCH STATION

East Malling, Near Maidstone, Kent

Director: F. R. Tubbs, M.Sc., Ph.D., A.R.C.S., D.I.C., F.L.S.

Advisers to Director: T. N. Hoblyn, O.B.E., Hort.Dip.,
R. V. Harris, D.Sc., A.R.C.S., D.I.C.,

Assistant to Director: H. B. S. Montgomery, B.A., Ph.D., D.I.C.

POMOLOGY

Head of Department: W. S. Rogers,
M.A., Ph.D., D.Sc., Dip.Hort., A.Inst.P.
Miss A. B. Beakbane, B.Sc., Ph.D., N.D.H.
R. J. Garner, M.Sc., N.D.H., Dip.Hort.
R. L. Knight, O.B.E., Ph.D., D.Sc., A.I.C.T.A.,
Dip.Agric.
Miss I. Modlibowska, Ph.D., Dip.Hort.
Miss B. G. Mosse, B.Sc., Ph.D., Dip. Hort.

STATISTICS

Head of Department: S. C. Pearce,
B.Sc., Ph.D.

PLANT PHYSIOLOGY

Head of Department: H. W. B. Barlow, B.Sc.
D. H. Maggs, B.Sc.

BIOCHEMISTRY

Head of Department: A. E. Flood,
M.A., Ph.D.

FRUIT NUTRITION

Head of Department: D. W. P. Greenham,
M.A., Ph.D.
Miss A. V. Delap, B.A., B.Sc.
J. E. Goode, B.Sc.

PLANT ANALYSIS

Head of Department: A. C. Mason,
M.Sc., F.R.I.C.

Secretary: T. R. Littlehales

PLANT PATHOLOGY

Head of Department: R. V. Harris,
D.Sc., A.R.C.S., D.I.C.
Deputy Heads: A. F. Posnette, M.A., Ph.D.,
A.I.C.T.A.,
J. E. Cross, B.Sc., Ph.D.
D. S. Kirkham, B.Sc., Ph.D.
J. T. Legg, B.Sc.
M. H. Moore, M.Sc., Ph.D., Dip.Hort.
P. W. Talboys, B.Sc., Ph.D., D.I.C.

ENTOMOLOGY

Head of Department: A. M. Massee,
O.B.E., D.Sc., F.R.E.S.
Deputy Head: G. H. L. Dicker,
B.Sc., Ph.D., A.R.C.S., F.R.E.S.
Miss E. Collyer, B.Sc., Ph.D.
L. A. Lickerish, B.Sc., M.A.
R. C. Muir, B.Sc.
R. S. Pitcher, B.Sc., Ph.D.,
Dip.Agric., Dip.Entom.

PLANT PROTECTIVE CHEMISTRY

Head of Department: A. H. M. Kirby,
M.Sc., Ph.D., A.R.I.C.
R. P. Tew, B.Sc., F.R.I.C.
M. Allen, B.Sc.

SCIENTIFIC LIAISON

Head of Department: H. B. S. Montgomery,
B.A., Ph.D., D.I.C.
F. W. Andrews, Ph.D., D.Sc., A.R.C.S.

Librarian: S. R. Ball, B.A., F.L.A.

The objects of the Institute are to solve the problems arising out of the growth and culture of fruit plants through the elucidation of the principles underlying cultural operations such as pruning, propagation, the use of root-stocks, manuring, soil treatments, etc., in relation to the growth and physiology of the tree, together with study of the problems involved in the control of the pests and diseases of fruit and certain diseases of the hop, and in the maintenance of the health status of propagation material.

On 31st March, 1958 the scientific and experimental staff of the Station numbered seventy-three.

CURRENT WORK

New planting material. One of the end points of research at East Malling, either deliberately sought or arising as a by-product of more fundamental investigations, is the production of improved planting material and the making of it available to the fruit and hop grower.

In this respect the year under review has been notable in several particulars: a new apple rootstock has been described, new selections of the Royal Sovereign strawberry and of the Loganberry have been made available to the Nuclear Stocks Association and three new varieties of hop, tolerant to progressive Verticillium wilt, have been released to the specialist commercial hop propagators.

The new apple rootstock, M.26, is a selection from among seedlings resulting from the "M.IX crosses," the aim of which was to add to our knowledge of the inheritance of rootstock characteristics enabling the control of tree size and precocity in the scion variety. This early work provided an opportunity to make improvements on the M.IX rootstock in respect of such characters as anchorage and yield and to extend the existing range of dwarfing and semi-dwarfing stocks. M.26 is intermediate in vigour between M.IX and M.VII, does not sucker, and has the additional advantage of improved resistance to apple mildew and to collar rot (*Phytophthora cactorum*). Having been found by test to be free from the rubbery wood and mosaic viruses, M.26 is being given further observation and trial with a view to decision on release.

The new clonal selection M.415 of Royal Sovereign, just released, has given better results in yield trials than the morphologically indistinguishable parent selection in circulation (M.48). The comparison was made with heat-treated virus-free samples of the old selection and the new re-selection; the latter thus provides a striking example of the value of re-selection on high yield as well as health criteria. Further tests of the relative merits of M.415 and M.48 are in progress.

The serious plight of Loganberry culture in this country is primarily related to the decline in vigour of the available planting stocks over the past two decades; research results now relate this to widespread infection with a virus detectable only by graft tests using a sensitive indicator. In collaboration with Long Ashton Agricultural and Horticultural Research Station a graft-tested re-selection from the original Malling clone of Loganberry made available from Long Ashton has been propagated and made available to the Nuclear Stock Association. Further promising selections of this and related hybrids selected on both pomological and pathological criteria, are in course of trial and development.

The demand for new varieties of hop which can be cropped on wilt infected land has become urgent as a result of the growing unpopularity of the early wilt-tolerant Salmon variety, Keyworth's Midseason, with the brewing industry. To meet this need East Malling has, since 1950, made extensive tolerance and cultural trials of selected seedlings produced as a by-product of an attempt to breed wilt-tolerant male hops. Three of these, chosen on the basis of cultural trials, and of brewing trials organised by the Institute of Brewing, have been named and released to approved commercial propagators for development under the appropriate Ministry certificate of health. The long-term programme of breeding for wilt-tolerance, developed jointly with Wye College, is now well advanced.

Breeding for resistance to pests and diseases. Breeding work, with the aim of producing apple scion varieties resistant to Woolly Aphis and of raspberries resistant to one of the principal aphid vectors of *Rubus* viruses, *Amphorophora rubi*, has continued. That some varieties of raspberry have a high virus disease-escaping ability has been well known for some time. An attempt to incorporate this useful character into new seedlings by breeding with resistant varieties of raspberry and other *Rubus* spp. is giving promising results.

Selection for Woolly Aphis resistance will in future be assisted by the discovery of a relationship between resistance and certain visually identifiable anatomical and chemical characters of apple stems.

A serious newly identified bacterial disease of pears. Research on bacterial diseases of fruit has been largely concentrated upon an intensive study of outbreaks, in 1957 and 1958, largely in Kentish orchards, of a severe cankering disease of certain varieties of pear. The symptoms and pathogen of this disease have been determined, and the latter appears to be identical with that of

the fire-blight disease in North America and New Zealand. Drastic measures to eliminate it from this country, or at least to reduce the risk of major economic damage to the pear industry are in course of formulation by the Ministry of Agriculture, Fisheries and Food, in consultation with East Malling Research Station.

This brief review necessarily omits many important research projects in which steady progress is being made. Further information is to be found in the Station's Annual Report.

AGRICULTURAL AND HORTICULTURAL RESEARCH STATION Long Ashton, Bristol

Director: Professor H. G. H. Kearns, O.B.E., B.Sc., Ph.D., Dip.Agric.

POMOLOGY

Head of Department: L. C. Luckwill,
B.Sc., Ph.D.

D. L. Abbott, B.Sc.

E. W. Hobbs, B.Sc., N.D.H.

R. R. Williams, B.Sc., Dip.Hort.sci.

NUTRITION OF FRUIT CROPS

Head of Department: C. Bould, M.Sc., Ph.D.

D. G. Hill-Cottingham, M.Sc., A.R.I.C.

CHEMISTRY

Head of Department: J. T. Martin,
D.Sc., Ph.D., F.R.I.C.

D. Woodcock, D.Sc., Ph.D., F.R.I.C.
(Organic Chemistry)

W. D. E. Thomas, B.Sc., Ph.D., F.R.I.C.
(Physical Chemistry)

E. Somers, M.Sc., Ph.D.

E. J. Skerrett, Ph.D., A.R.I.C.

C. P. Lloyd-Jones, B.Sc., A.R.I.C.

ENTOMOLOGY

Head of Department: H. G. H. Kearns,
O.B.E., B.Sc., Ph.D., Dip.Agric.

S. H. Bennett, B.Sc., Ph.D.

N. G. Morgan, B.Sc., Ph.D.

A. Stringer, B.Sc., A.R.C.S.

C. G. L. Furmidge, B.Sc., Ph.D., A.R.I.C.

PLANT PATHOLOGY

Head of Department: R. W. Marsh, M.A.

R. J. W. Byrde, B.Sc.(Hort.), Ph.D.

A. T. K. Corke, B.Sc., Ph.D.

Secretary: A. L. Leggett, A.C.A.

PLANT PHYSIOLOGY

Head of Department: E. J. Hewitt,
B.Sc., Ph.D., A.K.C.

CIDER AND FRUIT JUICES

Head of Department: A. Pollard, M.Sc., Ph.D.

G. C. Whiting, B.Sc., Ph.D.

Miss M. E. Kieser, B.Sc., A.R.I.C.

L. F. Burroughs, B.Sc., Ph.D., A.R.I.C.

F. W. Beech, B.Sc., Ph.D., A.R.I.C.

C. F. Timberlake, M.Sc., A.R.I.C.

J. G. Carr, B.Sc., Ph.D.

DOMESTIC FOOD PRESERVATION

Head of Department: Miss B. A. Crang,
B.Sc.

WILLOWS

Head of Department: K. G. Stott, B.Sc.

STATISTICS

Head of Department: G. M. Clarke,
M.A., Dip.Stat.

SCIENTIFIC LIAISON

Head of Department: M. Greenwood,
O.B.E., M.Sc.

Librarian: P. R. Colegate

Long Ashton Research Station, which is administered by the University of Bristol, studies all aspects of fruit growing, with special reference to the problems of growers in the West Midlands and the South-west. The main subjects of research include the breeding of cider apples and black currants; seedling and clonal rootstocks; hormones and synthetic growth-substances; the mineral nutrition of fruit plants; cultural systems for fruits; insect pests, fungus and virus diseases and their control; techniques in spray application; the manufacture of cider, perry and fruit juices; the chemistry and microbiology of fruit juices and fermented products; domestic methods for the preservation of fruit, vegetables, meat and poultry; willow growing and the utilization of basket willows. The Station serves as an advisory centre for cider making, cider orcharding and willow growing.

Research staff includes thirty-two graduate Scientific Officers, assisted by thirty-six Experimental Officers. A report on the work of the Station is published annually.

CURRENT WORK

Pomology and Plant Breeding. Pollination studies have shown the pear variety Bristol Cross to be virtually male-sterile, over 90 per cent of its pollen grains aborting at an early stage. With apples, the nitrogen status of the pollen source has been found an important factor in fruit setting.

Surveys of Somerset and Gloucestershire cider orchards have shown that virus diseases are particularly widespread where headworking has taken place; as the first stage in the provision of healthy propagating material, scion trees of the recommended varieties of cider apple have been tested for their virus content. The virus nature of "chat-fruit" in Lord Lambourne apples has been confirmed by graft transmission.

Auxin metabolism in the fruit of the fig has been found to be closely correlated with the development of the endosperm. 2:4:5-trichlorophenoxybutyric acid has been proved effective for the control of bindweed in black currants.

Plant Nutrition: Fruit. In field experiments with iron chelates for the control of lime-induced chlorosis of pears, Chel-138, which is particularly stable in calcareous soils, has again given good results from surface soil applications of 1 g. iron per tree or foliar sprays at 0.1 per cent. Trials of two synthetic soil conditioners with strawberries at Long Ashton and Efford showed that neither increased fruit yield, though both improved soil structure and aggregate stability.

Factorial sand culture experiments to determine the relation between leaf composition and nutrient requirement of fruit crops were started with strawberry, in which optimum growth and yield were associated with a dry-weight content of 0.3 per cent phosphorus in leaves at the time of fruiting.

Chemistry. The effect of molecular structure on biological activity has been studied in growth-regulating substances derived from 2-naphthylloxyacetic acid and in fungicides related to 8-hydroxyquinoline. A previously unreported compound, whose structure is being determined, has been isolated from Derris and Lonchocarpus resins.

Radioactive tracers have been used to study the movement of growth-regulators in plants and of chelates in calcareous soils, the role of iron and molybdenum in the metabolism of micro-organisms and the behaviour of copper fungicides on leaf surfaces.

Methods of analysis have been developed for the determination of DDT and chlorobenzilate occurring together in spray deposits, and for surface and absorbed deposits of mercury; the second method has been used to measure the accumulation of mercury on Bramley leaves and fruits sprayed with mercurial fungicides. Plant waxes have been further studied in relation to fungistatic effects and the solubilization of copper fungicides on leaf surfaces.

Entomology. Work with insect pests has included population studies of the aphids and leaf hoppers infesting apples, and records of the insects transmitting brown rot.

An investigation of wetting agents has shown that ionic surface-active agents are far more phytotoxic than non-ionic agents. Techniques are being developed for the use of fluorescent materials as tracers in insecticide formulations.

The production of spray droplets is being studied by means of a vibrating reed sprayer. A compressed-air spray nozzle has been designed that produces a more uniform pattern of fine droplets.

At the request of the Colonial Office, assistance has been given in the control of pests of coconuts in Kenya and the Solomon Islands and of *Abaca* hemp in North Borneo.

Plant Pathology. Work on the mechanism of fruit resistance to brown rot (*Sclerotinia fructigena*) has shown that the pectolytic enzyme activity of this fungus is suppressed by oxidised *l*-epicatechin, one of the phenolic components of apple fruit.

It was found that *Gloeosporium perennans* produced its ascospore stage (*Neofabrea malicorticis*) on detached apple shoots and on stubs. Reduction of sporing on *Gloeosporium* cankers was obtained by applying formulations of 0.3 per cent phenyl mercury chloride.

Studies on apple mildew have demonstrated the prolonged period of susceptibility of the vegetative terminal buds: overwintering infection on fruit buds was reduced to one-sixth of that on unsprayed trees by post-blossom applications of lime sulphur.

Cider and Fruit Juices. Vintage trials and chemical studies of fruit varieties have continued in conjunction with the programme of cider and perry orchard improvement. Work on the chemical components of fruits and juices has led to the isolation and identification of compounds of metabolic importance: new amino acids and organic acids have been isolated.

Complexes between metals and fruit components have been studied in further work on the behaviour of metals in fruit juice systems.

Microbiological investigations of the behaviour of individual yeasts, lactic and acetic bacteria, in fermentation, have led to improvements in cider making practice. The metabolic activities of individual cider yeasts have been studied, notably yeasts synthesising malic acid or producing pectolytic enzymes.

Domestic Food Preservation. The methods of preservation tested in this Section at Long Ashton have been described in the Ministry of Agriculture, Fisheries and Food Bulletin "Domestic Preservation of Meat and Poultry", published in April, 1958. Accounts of the microbiological work and of the process tests undertaken during the preparation of the bulletin have also been published.

Tests of the preserving qualities of varieties of fruits and vegetables, and of the effects of spray residues on fruit quality, have continued.

Willows. The variety *Salix aquatica gigantea* has been imported for an investigation of its suitability for conversion to paper pulp. Further studies have been made of the root systems of basket willows growing on different types of soil, of fungicides for the control of willow rust (*Melampsora amygdalina*) and of selective weedkillers for use in willow beds. By exposing cut willow rods to controlled temperatures and regulated day-length it has been possible to make them peelable two months earlier than untreated rods.

Statistics. Experimental layouts have been designed for spraying, pruning and virus transmission trials with dwarf pyramid apples at Long Ashton and for a cider variety trial in Herefordshire in which the risk of intermixing the crop from adjacent trees has been minimised.

Diagrams prepared in 1955 for the field assessment of black currant leaf spot have proved helpful in determining varietal susceptibility to the disease.

The possibility of expressing mathematically the shape of moving droplets is being investigated in collaboration with Rothamsted Experimental Station.

A.R.C. UNIT OF PLANT NUTRITION (MICRO-NUTRIENTS) Long Ashton, Bristol

Honorary Director: Professor T. Wallace, C.B.E., M.C., D.Sc., F.R.I.C., V.M.H., F.R.S. (Emeritus Professor of Horticultural Chemistry, Bristol University)

Senior Scientific Staff:

PLANT PHYSIOLOGY

E. J. Hewitt, B.Sc., Ph.D., A.K.C.

NUTRITION OF MICRO-ORGANISMS

D. J. D. Nicholas,
D.Sc., Ph.D., A.K.C., F.R.I.C.

PLANT BIOCHEMISTRY

H. E. Davenport, B.Sc., Ph.D.

ORGANIC CHEMISTRY

A. H. Williams, M.A., B.Sc.

INORGANIC CHEMISTRY

H. M. Stevens, B.Sc., Ph.D.

SOIL BIOLOGY

R. A. Webb, B.A., D.Phil.

The objects of the Unit are to determine the role of micro-nutrients in the metabolism of higher plants and micro-organisms and to relate these functions to the effects of micro-nutrients have on the growth of crops.

On 31st March, 1958, the scientific and experimental staff of the Unit numbered 20.

CURRENT WORK

The following are among the items of interest in the year's investigations.

Plant Physiology. Studies have been continued on the nitrate reductase enzyme which catalyses the reduction of nitrate to nitrite, with special reference to the effects of certain antimetabolites known to inhibit the synthesis of proteins and nucleic acids. The inhibitors, which included amino acids, purines, pyrimidines and natural antibiotics, were introduced into detached leaves of cauliflower and mustard by vacuum infiltration; three were found which markedly inhibited induced enzyme formation. When plants were grown with nitrate as the source of nitrogen, cessation of the nitrogen supply for 24-48 hours resulted in a rapid decline in nitrate reductase activity.

Nutrition of micro-organisms. The four enzymes involved in the assimilation of nitrate in the fungus *Neurospora crassa* have been characterized and shown to be flavoproteins dependent on metals for their formation and activity. In the nitrogen-fixing bacteria *Azotobacter vinelandii* and *Clostridium pasteurianum* the enzyme that fixes atmospheric hydrogen (hydrogenase) was shown to be a flavoprotein containing iron. The mode of cysteine formation from sulphate, sulphite or thiosulphate was determined for several fungi.

Biochemistry. In normal leaves of higher plants the ratio of chlorophyll to haematin was found to be remarkably constant and independent of the species. This relationship between the levels of the two types of metalloporphyrin was maintained in chlorotic leaves in which chlorosis had been induced by various micro-nutrient deficiencies. In iron-deficient leaves, the level of total iron was found to determine the concentration of the metalloporphyrines. An exception to this general picture was observed under conditions of manganese deficiency where, in certain plant species, decrease in chlorophyll was not accompanied by a corresponding decrease in total haematin.

Organic Chemistry. Investigations are in progress to determine the nature of phenolic substances in various parts of apple and pear trees.

Inorganic Chemistry. The fluorescent properties of metallo-oxine compounds were determined, as well as those of metal-riboflavin systems; the latter group provide important models for the flavoprotein enzymes.

Soil Microbiology. The effects of mineral deficiencies, and different types and amounts of organic matter, on the activity of soil micro-organisms have been

further studied. Large differences in microbial activity were associated with changes in the supply of organic matter, and activity was reduced by deficiencies of mineral nutrients.

The level of activity of the micro-organisms affected the rates of formation and breakdown of crumb structure in the soil. The proportion of soil aggregates was also related to the solubility of essential mineral nutrients.

SCOTTISH HORTICULTURAL RESEARCH INSTITUTE

Mylnefield, Invergowrie, by Dundee

Director: T. Swarbrick, M.Sc., Ph.D.

PLANT PATHOLOGY

C. H. Cadman, B.Sc., Ph.D., F.R.S.E.

CROP PHYSIOLOGY

G. L. Hodgson, M.A., D.Phil.

C. G. Guttridge, B.Sc., Ph.D.

VEGETABLE CULTURE

C. North, B.Sc., M.Sc., Ph.D.

MYCOLOGY

A. R. Wilson, B.Sc., M.S., Ph.D.

POMOLOGY

C. A. Wood, B.Sc., Ph.D.

WEST OF SCOTLAND UNIT

Auchincruive, Ayr.

R. D. Reid

Miss I. G. Montgomerie, B.Sc., Ph.D.

Secretary: A. B. Ross, A.I.A.C.

The problems under investigation arise from the Scottish horticultural industry. Since in general the Scottish climatic complex favours soft fruit and vegetable growing rather than top fruit, the work is directed mainly to a solution of the major problems limiting soft fruit and vegetable production in Scotland. The Institute is still very young, certain departments are only partially developed and the staffing of others has not yet begun.

On 31st March, 1958, the scientific and experimental staff numbered twenty-six.

CURRENT WORK

Virology. The main effort is directed to a study of certain soil-borne virus diseases found to occur in Scotland. It is now known that at least three of these particular diseases or closely related ones occur in many places in Scotland and throughout northern Europe, infesting raspberries, strawberries, sugar beet, potatoes, certain top fruits and a wide range of "weed" plants. The indications are that spread through the soil—as distinct from spread by a free flying insect vector—is much more common than was previously thought. The findings of these investigations have an immediate bearing upon cultural practice in fruit plantations and the conditions governing certification schemes aimed at providing planting stocks. These studies have made particularly urgent a more intensive study of the viruses themselves as distinct from the diseases which they cause.

Pomology (Fruit Culture). A large part of the work of this department is concerned with the effect of such cultural practices as soil management, manuring, pruning and planting density, as well as of varietal characteristics upon yield and fruit quality. The first series of experiments is now yielding results capable of immediate practical application in the industry.

An equally important part of the department's work is the breeding of new varieties and an intensive breeding programme in *Rubus* and *Ribes* is under way. This includes breeding for resistance to one or more of the soil-borne viruses mentioned under Virology section above.

Vegetable Culture. The work of this department is now well under way. Peas for canning and quick-freezing are an important crop in Perth-Angus and investigations into varieties suitable for these uses and means of estimating the best harvesting dates have been carried out for the last few years. The problems of growing economic crops of spinach and French beans in Scotland are also being investigated. The work also includes a study of the effect of environment upon the non-heading (bolting) of cabbage, lettuce, etc.

Mycology. This department is making a study of the fungus *Botrytis* and the diseases which it causes in raspberry, strawberry and glasshouse crops in Scotland. Particular attention is being paid to the effect of environment upon the fructification of the fungus under field and glasshouse conditions.

Crop Physiology. This department has two main streams of work. One is an attempt to analyse and specify the relative importance of the main factors making up the climatic complex of Scotland. The second is a study of the effect of environment upon flower and runner initiation and development in the strawberry.

Genetics. This department is undertaking a study of the inheritance pattern of the "yellows" complex in the strawberry. Upwards of 10,000 seedlings of a considerable number of families are now under continuous observation in the field. A study is also being made of the use of ionizing radiation and certain chemicals as a means of inducing desirable mutations in strawberries, raspberries, black currants and brassicae.

West of Scotland Unit. Strawberry breeding aimed at producing high yielding varieties resistant to attack by the root rotting fungus *Phytophthora fragariae* comprises the main endeavour of this unit. The two varieties recently released by the Institute, viz., Talisman and Redgauntlet, have both found satisfactory commercial acceptance. The fungus is itself mutating and new physiologic races must be expected to arise from time to time. A wider choice of genes for resistance is being sought and more rapid methods of initial testing for resistance are being developed.

OUTCOME OF RESEARCH

The Virology research has enabled the Institute to produce small stocks of the more important varieties of raspberry free from the virus diseases spread by free flying insects. Present research on soil-borne viruses is certain to affect the conditions governing the granting of certificates of health but it is too early yet to forecast what these changes will be. The work of the Pomology department has shown that of the six varieties in commerce today, Malling Jewel, Malling Promise, Lloyd George and Malling Exploit may be expected to give high yields most frequently. A compromise planting distance of 6 ft. 0 ins.—6 ft. 6 in. between the rows with plant stools 2 ft. 0 in. apart is expected to be satisfactory under a wide range of conditions. The Department of Vegetable Culture has published its results on the trials with peas and spinach and is making good progress in developing sure heading, hardy cabbage and Brussels sprouts suitable for growing in this northern latitude. The strawberry varieties Talisman and Redgauntlet have now been widely accepted commercially and together account for about half the total strawberry production in the United Kingdom.

The main results of the Institute's work are given each year in its Annual Report.

WYE COLLEGE

Department of Hop Research

Wye College (University of London), Ashford, Kent

Head of Department: H. S. Darling, B.Sc., M.Agr., A.I.C.T.A.

Senior Scientific Staff:

F. C. Thompson, B.Sc., M.Sc. (Agric.), A.R.I.C. R. A. Neve, B.Sc. (Agric.), Dip.Agric.Sci.

The Department of Hop Research is concerned with all aspects of hop production other than virus diseases and *Verticillium* Wilt which are the responsibility of East Malling Research Station. The main lines of hop research at Wye cover plant breeding; inorganic and organic chemistry including plant nutrition and resin formation; hop pests; Downy Mildew Disease; and crop growth. Hop picking by machine and hop drying are being studied at Wye by staff of the National Institute of Agricultural Engineering in collaboration with the Department of Hop Research. On 31st March, 1958 the scientific and experimental staff of the Department numbered nine.

CURRENT WORK

The hop breeding work is at present mainly directed towards the production of varieties that are tolerant to Progressive Wilt and that are of acceptable commercial quality. A series of promising seedlings of high tolerance produced by conventional breeding methods are being bulked up for farm trials. Polyploid breeding techniques, designed to facilitate the combination of disease resistance with the brewing quality of accepted commercial varieties, have been developed. The initial results obtained are encouraging. Such methods result in triploid varieties which produce cones with a low seed content when grown under English conditions of heavy pollination. This lack of seed may prove to be an advantage from both the cultural and the brewing point of view.

The mineral nutrition of the hop plant is being studied both by pot and barrel culture methods and by manurial trials of factorial design recently laid down on a range of soils in Kent and Sussex. One of the objects of this work is to study the relationship between crop yield and the nutritional status of the soil and the mineral content of the plant. Investigations are in progress on the weight of spray deposit per unit area of leaf given by applications at different volumes per acre of standard weights of chemical using air-assisted spraying techniques. Studies in organic chemistry, making use of chromatographic techniques, include investigations on the effects of introducing systemic organic compounds into the plant.

Research on hop pests includes studies on the performance of systemic insecticides. Recent examination of yield data from several East Kent farms has produced evidence which suggests strongly that these insecticides (which have been highly successful in controlling the Hop Aphis and Hop Red Spider) have increased the amount of green cones necessary to give a standard weight of dried hops.

Work on Downy Mildew Disease is gathering momentum. Investigations at present are mainly directed towards elucidating the way in which the fungus (an obligate parasite on hops) carries over the winter and infects new growth in the spring. Work is also being carried out on the establishment of laboratory techniques to measure varietal resistance to the disease with the object of assisting plant breeding research on the production of resistant varieties.

Growth studies on hops by a crop physiologist have recently been initiated at Wye. Many problems here await investigation, including that of growing hops for the picking machine. Preliminary research includes studies on an accepted commercial variety growing under normal field conditions with a range of

cultural treatments. Work has also been carried out on propagation in relation to plant and seed dormancy.

Research on hop drying at Wye is concerned with factors likely to prove important in the development of continuous drying installations using high air-speeds and high temperatures. For this work extensive use is being made by the National Institute of Agricultural Engineering of the miniature electrically operated kilns which form part of the departmental equipment.

VEGETABLES

NATIONAL VEGETABLE RESEARCH STATION

Wellesbourne, Warwick

Director: JAMES PHILP, B.SC., PH.D.

Deputy Director: D. W. Wright, M.A.

Senior Scientific Staff:

PLANT BREEDING

Head of Department: J. C. Haigh,

B.SC., PH.D., A.R.C.S., A.I.C.T.A.

H. Holland, B.SC.

L. E. Watts, B.SC.

CHEMISTRY

Head of Department: F. Haworth,

B.SC., PH.D., DIP.AG.SCI., A.R.I.C.

S. P. Spragg, B.SC., PH.D.

PHYSIOLOGY

Head of Department: E. J. Winter,

M.C., M.SC.

J. K. A. Bleasdale, B.SC., PH.D.

IRRIGATION

Head of Department: E. J. Winter,

M.C., M.SC.

ENTOMOLOGY

Head of Department: D. W. Wright, M.A.

J. A. Dunn, M.SC.

G. A. Wheatley, B.SC.

PATHOLOGY

Head of Department: W. G. Keyworth,

B.SC., PH.D., A.R.C.S., D.I.C.

A. G. Channon, B.SC.

J. A. Tomlinson, B.SC., PH.D.

WEEDS

Head of Department: H. A. Roberts, B.SC.

STATISTICS

Head of Department: J. A. Nelder, M.A.

Secretary: G. Lesson, B.SC.(ECON.), A.C.I.S. *Librarian:* Miss B. M. Moore, N.D.D.H.

The Station and its Sub-Station at Paglesham, Essex, were established in 1949 with the primary object of helping the country to become more self-supporting in its food requirements, particularly regarding vegetables. The work of the Station has been directed towards the solution of important practical problems in a wide range of subjects and vegetable crops, and towards the acquisition of scientific knowledge which will lead to advances in the practice of vegetable production. The subjects of research fall into eight sections, namely the breeding of improved varieties, the improvement and maintenance of soil fertility, the investigation of factors affecting crop growth, the study of irrigation, the control of pests, diseases and weeds, and the improvement of field experimentation.

On 31st March, 1958, the scientific and experimental staff of the Station numbered thirty-four.

CURRENT WORK

The technique of inbreeding, followed by crossing of inbred lines, shows promise of producing hybrid varieties of Brussels sprouts and of onions with distinct improvements in crop uniformity and yield. So far, over four years deep cultivation has benefited spring cabbage, leeks and Brussels sprouts; farm-yard manure has given the highest yield response with a range of vegetable crops and has prevented deterioration of the soil structure; and one top dressing

of inorganic nitrogenous fertilizer produced a higher yield of spring cabbage than the same total quantity applied in three small doses.

Physiological studies are in progress on the competition between vegetable crops and annual weeds, and methods of shifting the balance in favour of the crop are being investigated. This work involves varying the spacing of the crops, the weed density and the timing of weeding operations. In the irrigation research, special importance is attached to finding out whether there are stages in the growth of vegetable crops at which they are particularly sensitive to moisture deficiency. The recognition of such stages would help greatly, not only in producing good crops but in making the most economical use of water supplies.

Low rates of the insecticide dieldrin, when rotavated into the top four inches of soil, have been found to give almost complete control of carrot fly on carrots for two years, thus providing a cheaper, more effective and more lasting treatment than those in use. It has been found that the fungal disease of watercress, crook root, can be controlled by the introduction of minute quantities of zinc into the water of the cress bed. A commercial method of control has been developed consisting of an application of zinc frit (powdered glass containing zinc) on to the floor of the bed. This treatment is effective over a cropping season.

Dinoseb (amine), an effective herbicide for the control of annual weeds in market garden peas, has been giving good results when used as a post-emergence spray with spring-sown field and broad beans; it is being tested also as a residual pre-emergence herbicide with various kinds of beans. In recent years, the damage done to vegetable crops by the drifting of certain herbicidal sprays has raised important new questions which cannot at present be answered satisfactorily. Detailed studies have been started, therefore, on the effects of these sprays on a wide range of vegetable crops so that the symptoms produced may be distinguished from those given by virus diseases and other causes.

In order to improve the accuracy of results from field experiments, more information is being obtained on the nature and extent of the many extraneous factors which reduce their accuracy.

Further information on the work of the Station can be obtained in the Station's Annual Reports.

WEEDS

A.R.C. UNIT OF EXPERIMENTAL AGRONOMY

Department of Agriculture, University of Oxford

Honorary Director: G. E. BLACKMAN, M.A. (Sibthorpean Professor of Rural Economy, Oxford University)

Assistant Director: E. K. Woodford, M.Sc., Ph.D., D.I.C.

SELECTIVE TOXICITY AND HERBICIDAL ACTION

J. G. Elliott, M.A.

J. D. Fryer, M.A.

K. Holly, B.Sc.(Agr.), Ph.D.

C. C. McCready, M.A., D.Phil.

Miss D. J. Osborne, M.Sc., Ph.D.

R. G. Powell, B.A.

Miss L. Reinhold, M.Sc., Ph.D.

L. Kasasian, B.Sc.

NEW CROPS—PARTICULARLY OIL SEED CROPS AND HYBRID MAIZE

E. S. Bunting, B.Sc., Ph.D.

The Unit of Experimental Agronomy is concerned with two broad fields of research. The first group of investigations is devoted to the development of chemical methods of weed control, together with fundamental studies of the

nature of selective toxicity and the factors which bring about selective action in agronomic practice. The second relates to analyses of the conditions and requirements which would allow of the successful introduction of new or unusual crops into British farming.

On 31st March, 1958 the scientific and experimental staff of the Unit numbered twelve.

CURRENT WORK

When a herbicide is applied to a weedy crop, the factors which singly or severally determine its selective action are specific differences in (a) absorption by the roots, (b) retention by the shoot, (c) penetration into the shoot, (d) transport within the plant, (e) localized accumulation and (f) the reactions of the chemical within the individual cells. In the year under review most emphasis has been placed on elucidating by means of radio-isotopic techniques some of the physiological conditions which control the uptake, penetration and transport of a range of phytotoxic compounds by different species. From the findings of members of both the Unit and the Department of Agriculture, it is clear that several different processes are involved in the movement of such compounds within the plant and that the extent of the movement differs widely with the chemical structure. The study of the processes of absorption is giving a new lead to the solution of the major problem of why some species are resistant and other species susceptible to the growth regulator type of herbicide.

The developmental work involving greenhouse, pot culture and field trials has been continued at the University Field Station and has again been supplemented by further field experimentation at sites in different parts of the country. The evidence now accumulating suggests that herbicides have an important part to play in the renovation of low-grade grassland. Under some conditions the combination of an initial application to kill the original sward and subsequent surface cultivation will allow of a much improved establishment of the renovating seeds mixture.

The use of 2-chloro-4, 6-bis (ethyl-amino)-S-triazine ("simazin") for the control of weeds in hybrid maize is now extending into agricultural practice and trials conducted in 1957-58 indicate that this compound is promising for weed control in field beans.

The investigations relating to new crops are at the present time mainly devoted to further evaluations of firstly hybrid maize for grain and silage production and secondly the opium poppy as a source of seed and alkaloids. Both projects have now reached the stage when selection and breeding is being undertaken to evolve the most suitable types for conditions in the southern half of England.

A.R.C. UNIT ON PLANT GROWTH SUBSTANCES AND SYSTEMIC FUNGICIDES

Wye College (University of London), Ashford, Kent

Honorary Director: Professor R. L. WAIN, D.Sc., Ph.D., F.R.I.C.,
(Professor of Agricultural Chemistry and Head of Department
of Physical Sciences)

Senior Scientific Staff:

C. H. Fawcett, M.Sc., Ph.D., A.R.I.C. D. M. Spencer, B.Sc., Ph.D.
F. Wightman, B.Sc., Ph.D.

The Unit, created in 1953, is concerned with fundamental investigations on growth substances and systemic fungicides and chemists and biologists work in close collaboration.

On 31st March, 1958 the scientific and experimental staff of the Unit numbered six.

CURRENT WORK

In the studies of substances that regulate plant growth, attention continues to be given to the relationship of chemical structure to growth-regulating activity, and to the way in which these substances act. Investigations have continued on the behaviour of natural and synthetic growth substances within plant tissues and on the breakdown of some of these materials by bacteria isolated from soil. Knowledge acquired about the action of enzymes in breaking down various substances within the plant has enabled progress to be made in building up molecules which are selective in their toxic action between plant species, the selective activity depending on the enzymes present. The selective activity previously shown to operate in homologous series of aryloxy- and indole alkane-carboxylic acids has been studied further and the underlying mechanism has been more clearly revealed. A new group of polynitro compounds has also been prepared and investigated.

Studies on chemical structure in relation to fungicidal activity have led to a new group of active compounds, the aryloxythiotrichloromethanes. Some of these have been shown to be fungicidal in the vapour phase and to possess low phytotoxicity. Preliminary experiments with these substances as volatile fungicides for control of *Gloeosporium* rotting of apples in storage have given promising results.

Further investigations have been carried out with arylthioalkanecarboxylic acids as systemic fungicides and progress has been made towards determining the chemical nature of the antifungal compound present in the stem and root tissue of *Vicia faba*.

PESTS & DISEASES

A.R.C. UNIT OF INSECT PHYSIOLOGY

Department of Zoology, Downing Street, Cambridge

Director: Professor V. B. WIGGLESWORTH, C.B.E., M.A., M.D., B.Chir., F.R.S.

Senior Scientific Staff:

W. A. L. David, M.A., Ph.D.

J. S. Kennedy, M.Sc., Ph.D.

A. D. Lees, M.A., Ph.D.

A. Milne, M.A., D.Sc., Ph.D., F.R.S.E.

J. W. L. Beament, M.A., Ph.D.

The Unit exists to carry out research on those aspects of the physiology of insects which are likely to prove of value in the agricultural field. Studies on the biology of aphids have been in progress for some years at the Entomological Field Station where the facilities permit the integration of field and laboratory methods. The Black Bean Aphid, *Aphis fabae* has been maintained in clonal culture for twelve years and work has developed along two main lines: the role of host-plant physiology in aphid ecology, and the analysis of migratory and host-finding behaviour.

On 31st March, 1958, the scientific and experimental staff of the Unit numbered ten.

CURRENT WORK

On both the woody winter host, Spindle, and on the herbaceous summer host, Sugar Beet, *A. fabae* feeds and multiplies more on growing and senescent leaves than on mature leaves; and the seasonal alternation between woody and herbaceous hosts arises more from the seasonal differences in the growth pattern

in their hosts than from any botanical preferences. It has been shown that similar small differences in the growth pattern of certain varieties of Field Bean can account for their relative resistance to *A. fabae*. Susceptibility also varies with the weather: water deficiency makes plants resistant to colonization, for the aphid relies on the turgor pressure in the plant to drive the sap up its fine food canal.

By cutting the aphid away from its mouth parts and leaving them embedded in the plant, the actual food, the phloem sap, can be collected as it exudes from the stump of the mouth parts. In this way the first direct study of aphid nutrition was carried out on the willow aphid *Tuberolachnus salignus*. The nitrogen content of the sap is high during growth and senescence, very low during the mature stage, with pronounced effect on the aphids' nutrition. Besides its effect on turgor pressure, water shortage can arrest growth and senescence in the plant. This can have far-reaching effects on the nutrition of aphids and may point the way to another possible mechanism of varietal resistance to aphids in crop plants.

It was observed that in the field, migratory aphids, *A. fabae*, *Myzus persicae* and *Brevicoryne brassicae* alight indiscriminately on all hosts and even from suitable hosts most of them take off again. This intense locomotor excitation is highly conducive to the dissemination of plant viruses. In order to study it an apparatus was devised in which the behaviour of the aphid in flight could be accurately recorded. It was found that locomotion, and feeding followed by reproduction, are "antagonistic" modes of behaviour. Either activity inhibits the other, but gradually the inhibited reaction becomes more powerful and appears with greater intensity when the opposing reaction is in turn inhibited. This is a principle of wide applicability in animal behaviour.

A.R.C. VIRUS RESEARCH UNIT Huntingdon Road, Cambridge

Director: K. M. SMITH, C.B.E., D.Sc., Ph.D., F.R.S.

Senior Scientific Staff:

R. Markham, M.A., Ph.D., F.R.S.

J. D. Smith, M.A., Ph.D.

The work of the Unit is concerned mainly with the investigation of viruses of plants, insects, and bacteria, and the diseases which they cause. In addition, because of their importance to viruses, the general properties of the nucleic acids from a number of sources are also being studied.

Work on the viruses of insects ranges from field investigations on the epidemiology of a number of viruses affecting economically important pests, such as the cabbage white butterfly and the pine sawfly, with a view to causing artificial epidemics, to fundamental research on the multiplication of insect viruses using electron microscopy and ultra-thin sectioning methods. The shape and general anatomy of some of these viruses are being investigated. Attempts are being made to culture insect viruses in tissue culture, and immunological studies are also under way.

The plant viruses are being studied both from chemical and from biological points of view. A number of purified viruses are under investigation with a view to finding out the nature of several unidentified constituents which have been recognised recently. This is being done using chromatographic methods combined with radioactive tracers. The effect of the host plant on the chemical composition of viruses is also being re-investigated. From the biological point of view, studies on the multiplication of viruses and on interference between viruses are in progress.

The work of the Unit on the nucleic acids has revealed the existence of a number of new constituents in the nucleic acids of bacteria and fungi, and of the

higher animals and plants. The distribution and nature of these substances is under investigation. It would appear that the virus nucleic acids are almost unique in their relative simplicity, and attempts are being made to find out some of the regularities in their structure by using radioactive substituents.

In addition to the more fundamental work carried out by the Unit considerable attention is paid to the maintenance of stocks of viruses of plants and of insects which are still under investigation, or which are used to provide material for chemical study. The Unit also undertakes the identification of a number of species sent in by various outside organisations, and supplies virus and other materials for scientific research as a courtesy.

On 31st March, 1958 the scientific and experimental staff of the Unit numbered eleven.

HILL FARMING

HILL FARMING RESEARCH ORGANISATION 48, Palmerston Place, Edinburgh, 12

Director: A. R. Wannop, O.B.E., B.Sc.(Agr.), B.Eng., F.R.S.E.

ANIMAL STUDIES

Head of Department: J. F. Robinson,
B.Sc. (Agr.)

J. N. Peart, M.Sc., B.Sc. (Agr.)

BOTANICAL STUDIES

Head of Department: R. F. Hunter,
B.Sc.(Agr.), Ph.D.

R. Hughes, M.Sc., B.Sc. (Agr.)

J. King, B.Sc. (Agr.), Ph.D.

I. A. Nicholson, M.Sc., B.Sc. (Agr.)

Secretary: R. S. Boyd

The Hill Farming Research Organisation exists to investigate the problems of the agricultural use of hill land, in order to obtain greater knowledge of the factors that limit production, of the ecology of hill grazings, of the nutritional needs of hill sheep and of the methods that can be adopted to secure greater output.

The scientific and experimental staff of the organisation at 31st March, 1958 numbered twenty.

CURRENT WORK

Animal Studies. There are large areas of hill grazings which, within the limits of present knowledge, are unlikely to give an economic return to efforts to improve their herbage; a central feature of the research directed at increasing production from these areas is a study of the winter nutrition of the hill ewe. The scarcity of palatable nutritious herbage on hills from January to April with the necessity to maintain hill flocks under these conditions limits both the numbers of ewes that can be maintained and their annual production. Any means of improving the diet during this period may lead first to increased production per ewe and then to an increase in flock numbers. A trial comparing various supplements to natural hill grazing was continued for a third season in the year under review and experienced different climatic conditions from those of the two previous seasons. Previously a highly significant response had only been obtained in ewes producing and rearing twin lambs, but with the severe climatic conditions prevailing at the end of the winter of 1957-58, ewes which had been fed supplements produced single lambs significantly heavier than ewes unfed and lamb mortality at birth was less.

The records from the Organisation's three research stations emphasise the extent as well as the diverse nature of the lamb losses at parturition and between birth and one month of age. Losses are heavier in twins than in singles, due to

smaller and less well developed lambs as well as to the tendency of some ewes to neglect one of a pair of twins. Losses are also heavier in male than in female lambs. In the spring of 1957 following a mild winter, herbage growth was early and plentiful. Lambs were well developed and heavy at birth and losses from dystokia were severe, although less in some breeds and types than in others, probably due to variations in conformation. Supplementary feeding during pregnancy must therefore be timed to give adequate but not over-development of the foetus.

Botanical Studies. Studies of the drainage of hill peat have advanced and the many problems associated with measuring the rate of run-off are being gradually solved. These arise from the large range in rates of flow and the presence of peat debris in the effluent which clogs the meters.

Encouraging results have been gained in the work on surface seeding of hill pastures using various methods of pre-treatment and in the use of selective or total herbicides in either improving the botanical composition of hill swards or preparing them for surface sowing.

Attention has been given to the use of a most promising new herbicide for bracken. If it proves successful, an important new field of work will open up dealing with the surface sowing of areas formerly densely covered with bracken. Meantime, the routine work involved in determining the cutting frequency required to maintain control of bracken continues. A study of the regional types found in heather in Britain has shown these to have marked differences, a fact which would be of importance in any attempt to introduce heather artificially.

Where hill pastures have been improved in the past, it has been the practice normally to fence and improve blocks of the hill. This is unsuitable for the poorer types of hill pasture, and a trial started this year is designed to test the value of improving by manuring and surface sowing many small areas dispersed and unfenced on the open hill. This work will be of particular value for extensive areas of hill land that cannot be improved by more conventional methods.

The study of the strains of *Rhizobia* found on hill pasture has continued in co-operation with the Edinburgh and East of Scotland College of Agriculture. In general these strains are of an inferior type and they may be a possible obstacle to the improvement of hill grazings by the use of manurial dressings alone. A few strains were however found which were as efficient as the best lowland strains and a study has begun to find if these increase after the fertility level has been raised.

The study of hill sheep behaviour continues. An interesting aspect of their behaviour which has appeared in an examination of the data so far collected is that the degree of dispersion of grazing varies very little throughout the year. This is thought to be a characteristic of flock behaviour and may explain why some breeds of sheep are more successful at certain stocking rates than are other breeds.

ANIMAL BREEDING

A.R.C. ANIMAL BREEDING RESEARCH ORGANISATION

Headquarters: Glenbourne, South Oswald Road, Edinburgh, 9

Director: H. P. Donald, D.Sc., Ph.D., F.R.S.E.

Consultant (Part-time): Professor R. G. White, C.B.E., M.Sc., F.R.S.E.

Senior Scientific Staff:

N. Bateman, B.Sc., Ph.D.

H. B. Carter, B.V.Sc.

J. G. Hall, M.R.C.V.S., Ph.D.

J. L. Hancock, M.V.Sc., M.R.C.V.S., Ph.D.

A. Jamieson, B.Sc., Ph.D.

J. W. B. King, M.A., Ph.D.

St. C. S. Taylor, M.A., Ph.D.

J. H. Watson, B.Sc., Ph.D.

G. Wiener, B.Sc., Ph.D.

G. B. Young, Ph.D., M.R.C.V.S.

Livestock Officers:

Pigs: G. R. H. Bishop, M.Sc., N.D.A.,
N.D.D.

Sheep: J. L. Read, B.Sc.

Cattle: D. Gibson, B.Sc., S.D.D.H., M.S.

Secretary-Treasurer: F. H. James

The objective of the Organisation is to acquire knowledge essential to the development by breeding of livestock of improved performance under both present and future husbandry conditions.

At 31st March, 1958, the scientific and experimental staff numbered forty-eight.

CURRENT WORK

Dairy Cattle. An experiment designed to permit a comparison of crossbred with pure bred dairy cattle has reached the stage of producing some three-breed crosses (of Friesians, Jerseys and Ayrshires) as well as two-breed crosses and purebreds. In terms of average yield of milk and average total butterfat in first lactations, three-breed crosses have been superior to the other two groups by about 40 lb. of butterfat but such is the variability in performance of dairy cows that this advantage cannot be statistically confirmed with the 32 three-breed crosses that have completed first lactations. More of them are being reared and, should their merit be established, their daughters will be available to test the hypothesis that a herd of such crossbreds can be self-replenishing.

The study of twin cattle, fraternal as well as identical, is proving most rewarding. Under experimental conditions in which the amounts and constituents of feed are carefully controlled it appears that the astonishing resemblance of identical twins is only partly due to their genetic identity. In some characters, such as juvenile weights and measurements and milk yield, the similarity of environments accounts for much of the resemblance. There is much more to this similarity than apparent uniformity of feeding and housing, for this applies to all animals and yet falls far short of complete environmental control for animals that are not close contemporaries and not reared literally side by side. Practical measures for reducing further the unwanted variation must await identification of its sources.

With the aid of twins, a study is being made of the process of growth. If this can be resolved into the three components, mature size, growth impulse at immature stages, and deviations from an animal's own ideal growth curve, more efficient methods may be devised for improving meat animals. Observations on solids-not-fat have shown that four of its principal constituents have heritabilities of the same order of size as butterfat percentage itself. They should respond, therefore, to selection pressure as butterfat percentage does.

Sheep. The Organisation's flock of Welsh Mountain sheep which runs on the Berwyn Mountains is providing a great deal of information about genetical

and environmental factors conditioning survival and performance. A large part of the ewe flock is mated to ram lambs (with no ill-effects on fertility) half of which have hairy birthcoats and half non-hairy birthcoats. This selection produces rapid and obvious effects—not only on birth-coats but also on adult fleeces. Rams with smooth birth-coats produce offspring with softer fleeces. An important object of the experiment, namely, to determine the survival rates of the two types of lamb, remains to be achieved. In another portion of the flock, however, the use of pedigree-type Welsh rams as opposed to mountain-type rams, although making birth-coats and fleeces softer, has little or no effect on survival and growth.

A selection experiment with Scotch Blackface sheep, aimed at revealing some of the factors in adaptation, is also providing some information on the problem of away-wintering of ewe hoggs. There can be, given a big enough difference in nutritional status between home and away-wintered hoggs, an immediate advantage to the latter in survival, body weight and fleece weight but it tends to fade away long before the cost of wintering is repaid. Consequently the deficiency, if it is to be justified, has to be met in some other less tangible way such as the benefit to the ewe flock from the lower winter stocking rate.

Pigs. Work with pigs has reached the stage of testing inbred lines in various combinations against outbred controls. The first and simplest comparison is of outbred and inbred boars as sires of litters from outbred sows of the same or a different breed. On present evidence it appears that the average inbred boar has no advantage over the average outbred boar for producing bacon pigs. Furthermore, although inbred boars from selected lines may do well when used in this way, the long-term prospect for them is not very encouraging and more effort is now being put into testing crosses of two or more lines with special emphasis on sow performance.

The breeding herd is also providing material for studies fundamental to the development of A.I. in pigs. By killing sows 2–4 days after natural or artificial insemination and counting fertilized and unfertilized eggs, the success or failure of service can be quickly related to variations in technique.

A.R.C. UNIT OF REPRODUCTIVE PHYSIOLOGY AND BIOCHEMISTRY

**Molteno Institute of Biology and Parasitology and School of
Veterinary Medicine, University of Cambridge**

Director: T. R. R. Mann, M.D., Sc.D., Ph.D., F.R.S.

Deputy Directors:

L. E. A. Rowson, O.B.E., M.R.C.V.S.
(Part-time)
A. Walton, B.Sc., Ph.D.

Senior Scientific Staff:

C. E. Adams, B.Sc., Ph.D.
J. C. Boursnell, B.Sc., Ph.D., F.R.I.C.,
A.R.C.S.
E. F. Hartree, M.A., B.Sc., Ph.D.
E. J. C. Polge, B.Sc. (Agric.), Ph.D.
R. V. Short, Ph.D., M.R.C.V.S.

On 31st March, 1958 the scientific and experimental staff of the Unit numbered nine.

CURRENT WORK

Several closely related lines of research have been followed during 1957–58, all concerned with the physiology and biochemistry of animal reproduction.

In experiments with semen, further evidence has been obtained that during storage of spermatozoa *in vitro*, fertility is lost much earlier than motility. The observation that apart from glycerol certain alcohols, sugars and amides also act successfully as protective agents during the freezing of semen, has stimulated new experiments in the technique of semen preservation by deep freezing. Biochemical studies on semen culminated in two new findings, (i) that spermatozoa are distinguished from other animal cells by an unusually high content of plasmalogen, an aldehydogenic lipid probably associated with sperm respiration, and (ii) that the seminal plasma of man, ram, bull, boar, stallion and rabbit, contains in addition to fructose a certain amount of sorbitol, a sugar-alcohol which the spermatozoa are capable of oxidizing rapidly to fructose.

In the field of endocrinological studies, one notable advance has been the application of a new chromatographic technique for progesterone assay in blood to investigations of the hormonal changes associated with pregnancy, parturition and abortion in domestic animals. Another finding, based on experiments with monozygous twin-calves, has been the demonstration that in young bull-calves the onset of fructose and citric acid secretion in the seminal vesicles can be greatly advanced by injections of gonadotrophin.

A new project of the Unit, on which work started a year ago, has been the study of the relationships between the embryo and its environment during early pregnancy, particularly at the crucial period immediately preceding and following implantation. With the aid of certain radio-active ions such as phosphate, sodium, potassium and iodine, administered parenterally, it has been possible to demonstrate the entry of such ions into the pre- and post-implantations embryo and into the tissues of the reproductive tract with which the embryo is in close association. Research was also continued on ovum transplantation, both in sheep and rabbit, and on the problem of foetal mortality. Among research projects concerning the foetus has been an attempt at inducing tissue tolerance in sheep by intra-foetal injections of lymphatic cells.

A.R.C. UNIT OF ANIMAL GENETICS

Institute of Animal Genetics, University of Edinburgh, Edinburgh, 9

Honorary Director: Professor C. H. Waddington, C.B.E., M.A., Sc.D.,
D.ès Sc., F.R.S.

Deputy Director: D. S. Falconer, B.Sc., Ph.D.

Senior Scientific Staff

QUANTITATIVE GENETICS

E. C. R. Reeve, B.A., Ph.D.

F. W. Robertson, Ph.D., D.Sc.

G. A. Clayton, B.Sc., Dip.An.Gen.

OPERATIONAL RESEARCH

Alan Robertson, B.A., D.Sc.

I. L. Mason, B.A.

MAMMALIAN GAMETES

R. A. Beatty, M.A., Ph.D.

At the end of 1945 the Council set up an organisation to apply genetical knowledge to the improvement of livestock breeding. One part of this has now developed into the A.R.C. Animal Breeding Research Organisation. The other part, which was concerned to develop those aspects of fundamental genetics that are particularly relevant to practical animal breeding, has since 1947 worked at the Institute of Animal Genetics, University of Edinburgh, under a variety of administrative arrangements. In October, 1957, the group was given the formal constitution of a research Unit. At that time its scientific and experimental staff numbered fourteen.

CURRENT WORK

The unit engages in two main types of research—a deepening of our understanding of fundamental genetical principles, particularly in fields closely connected with practical animal breeding; and the use of general scientific procedures in the analysis of the results of animal breeding as it is actually carried out in this country. Owing to its connection with the University, the Unit is also able to provide specialised training in animal breeding genetics at a post-graduate level. These three aspects of the Unit's work will be considered further in the paragraphs which follow.

Basic genetical problems related to animal breeding

The work under this heading is of four main types:—

- (a) *The genetics of quantitative characters in animals.* The variations which occur between essentially normal animals in such characters as size, growth rate, milk yield, general vigour, etc. are to some extent inherited but our scientific understanding of the heredity of such "quantitative" characters is still very scanty. It is quite impractical to attempt to develop fundamental scientific theory by means of experiments on such slow breeding animals as pigs and cattle. The Unit therefore devotes a considerable fraction of its time to the study of such problems in relatively fast-breeding laboratory animals such as the mouse and the fruit fly *Drosophila*. Extensive programmes of selection have been carried out, both with characters such as body weight or milk yield in mice which may be expected to be closely related to the general fitness and vigour of the animal, and with characters (such as the number of bristles on an abdominal segment of *Drosophila*) which may be of less crucial importance in the general physiology of the animal. Another major interest has been the study of the phenomenon of hybrid vigour or heterosis, and the closely connected question of the nature of inbreeding depression. Ten years work on both mice and *Drosophila* have yielded very extensive data, but these are not of a kind which can be summarised in a few lines. The experiments have revealed the great complexity of the genetical systems which control quantitative characters. In this hitherto rather neglected field of genetics, we are still at the stage of discovering all the factors which have to be taken into account, and have not yet reached the point at which a general theory is likely to be successful, although that time is beginning to look not too far distant. Certain specific points of particular interest can of course already be investigated for their own sakes. For instance, members of the Unit have used *Drosophila* or mice as models to test in practice, over a considerable number of generations, some of the procedures which have been suggested as useful in animal breeding such as reciprocal recurrent selection.
- (b) *Mammalian Gametes.* Another aspect of fundamental genetics of particular relevance to animal breeding is the genetical behaviour of the mammalian gametes. One group of workers in the Unit has been particularly concerned with several questions in this field. They have, for instance, studied the possibility of producing polyploid mammals, with more than the normal two sets of chromosomes, by the use of procedures which influence the behaviour of the chromosomes shortly before or after fertilisation. Considerable success was achieved in mice, although no polyploids have so far been brought to the point of birth. Again, it has been shown that several characters, both of the egg and of the sperm, are themselves under the control of genes in the animals in which these germ cells are produced or possibly of genes contained in

the cells themselves. Various experimental procedures may also influence the fertilising ability or other behaviour of the gametes. If it should prove possible to achieve detailed control over the essential biological functions of the gametes in fertilisation, results of great practical importance might follow.

- (c) *The genetics of evolutionary processes.* The study of the artificial selection employed in livestock breeding finds its natural complement in the investigation of the natural selective processes which operate in evolution; and the formation of breeds and strains in domestic animals finds its counterpart in the formation of local races and subspecies in nature. The Unit carries on some study of local races, especially in *Drosophila*. Particular attention has recently been paid to the experimental study of the effects of selection when powerful environmental influences are also operating. A process, which has been called genetic assimilation, has been revealed which goes far to explain, in orthodox genetical terms, the class of phenomena for which in the past many people had been tempted to invoke a Lamarckian explanation involving the inheritance of acquired characters.
- (d) *Developmental genetics and experimental embryology.* In the last analysis the output of the livestock industry depends on the capacity of animals to synthesise protein, which man may use in the form of flesh, milk, or wool. The ways in which this synthesis is carried out, and the part played by genetic factors in controlling it, are perhaps the most fundamental of the problems offered to the scientist by the livestock industry. They engage the attention of very many workers in many different laboratories. The Unit touches only a few aspects of this problem; in particular, it studies some of the cellular activities associated with the elaboration of proteins, and the role of the nucleus, with its genes, in these processes.

Operational research. Another major interest of the group has been the application of scientific methods to the evaluation of the results of animal breeding as it is carried out in normal practice in this country. Particular attention has been paid to the artificial insemination of dairy cattle and especially to the discovery of better methods of sire evaluation. The application of general genetical principles led to the formulation of a scheme which, with slight modification, has been adopted by the Milk Marketing Board as the standard way of assessing "Relative Breeding Value". The work of the group led to the proposal of a general scheme of operating an A.I. centre, and this has been put into operation under the auspices of the Council at Cambridge, one member of the Unit acting as the scientific adviser to the project. The operational research group has also worked on dual-purpose cattle, beef cattle, sheep and turkeys. It is essential that workers in such highly specialised and practical fields should preserve close contact with the fundamental science on which their insight into scientific method is based. The operational research group has accordingly been very active in the study of quantitative genetics in *Drosophila*.

Specialist training in animal breeding. The Edinburgh University Department of Animal Genetics, besides providing undergraduate training, offers a post-graduate Diploma which may be taken by students from other universities. This course allows for some specialisation and in practice a considerable number of the students entering on it wish to specialise in animal breeding. Although the framework of the course is provided by the members of the University department, some members of the Unit gave relatively short courses of lectures in their own special fields. The University department also provides post-graduate training for a considerable number of Ph.D. candidates, some 50 of whom have

passed through it in the past ten years. Many of these again wish to specialise in animal breeding, and in that case they may be attached to a member of the Unit as a part of his research team, and he then takes responsibility for detailed direction of their work. Some of these students come from the Commonwealth or from foreign countries, so that members of the Unit are brought in close touch with animal breeding problems throughout the world. Coming nearer home, it is perhaps relevant to remark that of the geneticists on the staff of the Animal Breeding Research Organisation, all but one received their training within the Group that has now become the Unit of Animal Genetics.

ANIMAL DISEASES

A.R.C. FIELD STATION

Compton, Newbury, Berks.

Director: W. S. Gordon, C.B.E., Ph.D., M.R.C.V.S., F.R.S.E.

PATHOLOGY

Head of Department: H. H. Holman,
D.Sc., Ph.D., F.R.C.V.S.

I. H. Pattison, B.Sc., M.R.C.V.S.

W. J. Hadlow, D.V.M. (Seconded from
U.S. Department of Agriculture)

BACTERIOLOGY

Head of Department: S. J. Edwards,
D.Sc., F.R.C.V.S.

A. McDiarmid, D.Sc., Ph.D., M.R.C.V.S.,
F.R.S.E.

J. D. Rankin, Ph.D., M.R.C.V.S.

R. L. Chandler, B.Sc., Ph.D., F.R.C.V.S.

J. M. Payne, B.Sc., Ph.D., M.R.C.V.S.

ANIMAL ECOLOGY

Head of Department: A. Brownlee,
B.Sc., M.R.C.V.S.

RADIOBIOLOGY

Head of Department: R. J. Garner,
M.A., F.R.C.V.S., M.V.Sc., A.R.I.C.
B. Sansom, B.A.

FARMS

Manager: E. V. Knight, O.B.E., B.Sc., N.D.A.

ISOLATION COMPOUND

Manager: J. Elliot, M.A. (Agric.)

Secretary: F. R. Meakins

The Field Station at Compton, an estate of 2,000 acres, is farmed intensively to produce feeding stuffs and animals of a known health history so that a flow of suitable cattle, sheep, pigs, goats and small laboratory animals can be maintained for the purpose of studying animal diseases.

At 31st March, 1958, the scientific and experimental staff of the Station numbered twenty-four.

CURRENT WORK

Contagious Bovine Abortion (Brucellosis). As previously reported, work is proceeding with a killed adjuvant vaccine prepared from *Brucella abortus* rough strain 45/20. The advantages of using this vaccine are that strain 45/20 does not produce agglutinins in the vaccinated stock and that the use of killed organisms makes the vaccine easy to prepare and store, and safe to handle. Initial trials have shown that two doses of this vaccine give an effective protection to cattle but produce a persistent and undesirable reaction at the site of inoculation which renders the vaccine unsuitable for general use. Methods by which this reaction may be decreased are being investigated, including the use of smaller volumes of the inoculum or of the adjuvant.

Mastitis in cows. It is now general experience in Britain and other countries that antibiotic therapy can keep bovine mastitis caused by *Str. agalactiae* under effective control. Treatment of staphylococcal mastitis, however, has been much

less successful and research into other methods of controlling this disease are being continued at Compton. In particular, an examination is being made of the possibility of prophylactic vaccination, and encouraging results have been obtained in preliminary trials in which goats exposed experimentally to the disease were used. Thus it has been found that vaccination of goats with a highly virulent strain of bovine staphylococcus gives protection against a test dose of the same organism. It has been noted, however, that this vaccine does not protect equally against all strains of bovine staphylococci, and work is in progress on the serological typing of different strains of this organism to gain knowledge of their antigenic structure and to determine what combination of strains must be present in a vaccine to provide protection against all the types associated with mastitis.

Johne's Disease. Work on the methods of infecting cattle experimentally is being continued and new experiments on infection by the oral route have been started. These are being carried out in three stages and when they finish, in about 4 or 5 years time, it is expected that a standard oral dose of *M. johnei* for cattle will be available. The use of the tannic-acid-haemagglutination test is being investigated, and observations on the complement-fixation test are being continued.

The possible use of small laboratory animals for some aspects of Johne's disease research is being explored including the possibility of lowering natural resistance by the use of cortisone.

Scrapie. Sheep from twenty-four different breeds have been tested for susceptibility to scrapie. Using the same inoculum throughout, the incidence of experimental infection varied widely from no cases in four breeds to 70 per cent. in the most heavily infected breed. Different families within a breed also show differences in susceptibility which can apparently be as great as that between breeds. It has recently been found that some of the progeny of parents inoculated with scrapie infective tissues may develop scrapie. This is an interesting advance and, if confirmed, will be helpful in future studies of the disease.

Further experimental inoculations of goats have confirmed the high percentage "take" in this species when compared with sheep, and this has greatly facilitated experimental work on the disease. Observations at present in progress, using goats as experimental animals, include the distribution of the infective agent in the body tissues at various times during the course of the disease, and the nature of the causal agent. Because of the facilities that exist at Compton for the study of scrapie, the United States Department of Agriculture has appointed Dr. W. J. Hadlow to the Field Station for a period of two years to extend the work on the pathology of the disease.

Polled Ayrshire Breeding Experiment. The grading-up in this project has now reached the stage where FR₃ (third backcross) heterozygous polled bulls are ready for mating with pedigree Ayrshire females to produce the FR₄. Polled FR₄ animals will then be mated *inter se* and 25 per cent of their offspring, which will be brown and white with approximately 97 per cent Ayrshire "blood", are expected to be homozygous polled.

While it now appears reasonably certain, on the evidence of large numbers of test-matings, that scurred males are always heterozygous for horns, it is not yet safe to assume that clean polled males are invariably homozygous and further test matings of clean polled bulls are being continued. Observations are in progress to determine if homozygosity for the polled character in females can be diagnosed.

It is intended to test-mate males with at least 16 of their daughters in an attempt to uncover inherited defects that may exist in the breed.

Animal Ecology. As it has been found that diet influences the development of rumen papillae in cattle, a study has been made of the influence of diet on the gastro-intestinal tract of laboratory rats. Rearing rats on a flesh diet resulted in a large intestine that was shorter and lighter than in the mash-fed controls. Rats restricted to one feeding time of 2½ hours each day acquired a heavier stomach than the unrestricted controls. In stock rats, organ weights expressed as a percentage of live weight fell with the increase in live weight. An exception to this rule was the breeding female; more work is being done on this. Work is also in progress on changes in the stomach microflora occurring with change of diet and with restriction of diet.

Dietary influences may be responsible for the production of pathological changes in omasal folds of cattle; these are being studied.

Clinical Pathology. Diseases occurring spontaneously among the large stocks of farm animals held at Compton are receiving clinical attention and investigation. Disturbances in the health of animals which may be required for experiment are recorded and treated. Complete laboratory investigations are made on the more problematic diseases. These include the rapidly fatal jaundice of housed sheep associated with high liver copper storage, and the encephalitis of housed sheep associated with the presence of *Listeria monocytogenes*.

Pneumonia in Pigs. The systematic study of agents responsible for pneumonia in pigs has been continued and developed to include observations on experimental co-infections that simulate the complex pneumonia syndromes occurring in the field. In this way it has been possible, with a number of agents, to assess their contribution to respiratory disease in the pig together with the clinical and histopathological changes attributable to them. The agents studied so far have included *Pasteurella*, *Corynebacterium*, *Haemophilus*, lungworms and "virus pneumonia."

The complete pathology of uncomplicated pig lungworm infection has been investigated from the viewpoints of pathogenicity and pathogenesis. Observations have been made on its aggravating effect on virus and bacterial pneumonia.

Observations on organisms of the *Haemophilus* group in pigs have shown that a characteristic pneumonia with pleurisy found in field cases infected with some strains of *Haemophilus*-like organism can be reproduced experimentally by intratracheal inoculation of pigs with pure cultures of the organism. This will enable progress to be made in further studies of this disease.

Haematology. The blood groups survey on selected cattle is being continued, and four isoimmune sera have been prepared in addition to the reagents originally provided. The study of the blood-picture of goats has been carried on over the year and will continue into next year.

Radiobiology. During the course of the year work has continued on the metabolism of ^{89}Sr and ^{131}I in the dairy cow. It has been shown that ^{89}Sr is equally available to the cow whether fed in the form of pile-produced material sprayed on to grass or absorbed on to cattle cake or in the form of debris collected from weapon clouds. A series of experiments designed to study the comparative metabolism of the alkaline earth elements (calcium, strontium and barium) has been set in hand. Preliminary work has shown that there is greater discrimination against barium than strontium during their passage from the diet to the milk. Suitable techniques for counting combinations of ^{45}Ca , ^{89}Sr and ^{140}Ba have been developed.

FOOT-AND-MOUTH DISEASE RESEARCH INSTITUTE

(Animal Virus Diseases)

Pirbright, Surrey

(World Reference Laboratory for Foot-and-Mouth Disease)

Director: Ian A. Galloway, D.Sc., M.R.C.V.S.

Deputy Director: J. B. BROOKSBY, D.Sc., Ph.D., M.R.C.V.S.

VACCINES

(a) *Inactivated Vaccines*: T. W. F. Pay,
B.Sc., M.R.C.V.S.

A. W. Morrow, M.A., B.Sc.

(b) *Attenuated Strains*: H. H. Skinner,
M.R.C.V.S.

SEROLOGY

J. B. Brooksby, D.Sc., Ph.D., M.R.C.V.S.

J. R. Haddow, O.B.E., B.Sc.,
M.R.C.V.S., D.V.S.M.

R. F. Sellers, B.A., B.Sc., M.R.C.V.S.

TISSUE CULTURE

W. B. Martin, M.R.C.V.S., D.V.S.M.

Secretary: A. C. T. Edwards, C.B.E., B.A.

PATHOLOGY AND EXPERIMENTAL CYTOLOGY

H. Platt, Ph.D., M.V.Sc., M.R.C.V.S.

GENETICS

H. S. Sharpe, B.Sc., Ph.D.

BIOCHEMISTRY

F. Brown, M.Sc., Ph.D.

Joan Crick, M.Sc.

BIOPHYSICS

C. J. Bradish, B.Sc., Ph.D., A.Inst.P.

H. V. Thorne, B.Sc., Ph.D., A.R.C.S.

DISEASE SECURITY OFFICER

H. Cronly, C.B.E., M.R.C.V.S.,
D.V.S.M., D.T.V.M.

The number of the scientific and experimental staff at the Institute on 31st March, 1958 was twenty-nine.

Epidemiological Surveys and Immunological Typing of Virus Strains. Reference was made in the 1956-57 report to the work of the Institute in carrying out the examination of suspected material from outbreaks of foot-and-mouth disease not only in this country and the Commonwealth but from all over the world.

The Institute recently reported results of the examination and immunological classification of 2,200 samples from 1948-1958 from outbreaks in countries in Europe, Africa, Asia and the Americas during which period four new types of virus were revealed. One of the recent steps taken following negotiations between the Food and Agriculture Organization of the United Nations and the British Government has been the establishment of a World Reference Laboratory for Foot-and-Mouth Disease at the Pirbright Institute. F.A.O. is seeking the co-operation of governments so that the surveys carried out at Pirbright will be continued and extended.

The functions of the World Reference Laboratory will include also the examination and classification of virus types and sub-types, the ultimate establishment of a collection of all types and confirmed sub-types and their corresponding antisera. It will give all possible assistance to countries in Europe and the Americas which carry out their own routine typing, if specially requested to do so, and will be responsible for the examination and identification of strains of virus suspected to be other than O, A and C.

CURRENT WORK

Vesicular Exanthema. Identification of the types of the virus of vesicular exanthema of swine has been carried further. On the basis of cross-immunity tests in swine, strains 1 and 101 (the "Pirbright" strains which originally came from America) were differentiated from the other 7 types of the virus from more recent outbreaks in the U.S.A. It has been confirmed therefore that there are at least 9 types of the virus. All type strains were established in tissue

culture on pig kidney monolayer cultures and characteristic differences in plaque size and morphology were noted. No correlation appeared to exist between plaque characters and virulence in swine. Serum neutralisation tests on pig kidney cell monolayers confirmed the cross immunity tests and the differentiation of the types. Type specific antisera for the nine virus types are now held at Pirbright in addition to antisera for the seven types of the virus of foot-and-mouth disease and two types of vesicular stomatitis for differential diagnosis from foot-and-mouth disease.

Agar Gel Diffusion Technique and Antigenic Analysis. Early in these studies it was found that two precipitin lines are formed when any of the virus types reacts with its homotypic antiserum. It has now been shown that the two lines correspond with the individual lines produced when the large (20 m μ) and small (7 m μ) components of the virus are diffused separately towards the homotypic antiserum. It has been possible also to obtain immunoelectrophoretic evidence for the presence of two precipitating antibodies in the immune serum. An important factor in the preparation of any inactivated virus vaccine is that the antigenicity of the virus should be retained as far as possible during the inactivation process. The achievement of this aim while at the same time ensuring the complete inactivation of the virus is often difficult.

Experiments were undertaken to determine whether a correlation could be found between the immunising value of the vaccine and the precipitin line pattern obtained with the agar gel diffusion technique. Several physical and chemical treatments of the virus were tested and others are being investigated. The results have shown that the agar gel diffusion test should serve as a useful screening test for virus inactivating procedures with a view to preparing the most effective vaccines and that any inactivating procedure likely to be useful should be capable of preserving intact the antigenic structure of the larger (20 m μ) component of the virus while completely inactivating the virus. Inactivating procedures which were carried too far to a point when only the precipitin line due to the smaller (7 m μ) component of the virus was produced yielded a preparation which failed to raise neutralising antibodies when injected into animals and had no immunising value.

The usefulness of the agar diffusion technique has been demonstrated also for the investigation of the virus sub-type problem. In addition to the seven main immunological types of the virus there are strains of the virus which differ sufficiently in antigenic structure to classify them as sub-types. A visiting worker, Dr. Graves from the U.S.A. (Plum Island Animal Disease Laboratory) in differentiating sub-type strains by both complement fixation tests and the agar diffusion technique has found that the pattern of cross reactivity given by the two methods is very similar. The agar gel diffusion technique has been applied not only to guinea-pig virus and antiserum but also to cattle virus and antiserum and similar differentiation of strains can be obtained. These results provide a useful contribution to epidemiological studies since they indicate that the agar gel diffusion technique would prove a useful method of examining virus from field outbreaks in certain areas in studies on sub-types.

Effect of Detergents on the Viruses of Foot-and-Mouth Disease and Vesicular Stomatitis and application to studies of the Virus of Foot-and-Mouth Disease. It has been shown that the virus of foot-and-mouth disease is highly resistant to the anionic detergent, sodium dodecyl sulphate (S.D.S.), the cationic detergent, cetyl trimethyl ammonium bromide (C.T.A.B.) and the non-ionic, Tween 80.

The resistance of the virus of foot-and-mouth disease to S.D.S. was found to be in marked contrast to the susceptibility of the virus of vesicular stomatitis. (The viruses of herpes, louping-ill, influenza, myxomatosis, vaccinia, lympho-choriomeningitis and Rous sarcoma, as reported by other workers, are also

inactivated by the detergent). The possibilities have been demonstrated of extracting virus from infected cells with S.D.S. in studies of multiplication of the virus of foot-and-mouth disease, in concentrating virus by elution from adsorbents and in increasing yields in ultracentrifugation of virus suspensions.

It is of interest in this connection that it has been recorded in the literature (Galloway, 1931) that the virus of foot-and-mouth disease is resistant to the action of a naturally occurring detergent, sodium desoxycholate, up to a concentration of 10 per cent. In this respect it resembles the viruses of poliomyelitis, encephalomyelitis, Coxsackie and encephalomyocarditis. The resistance of the virus of foot-and-mouth disease to ionic detergents and its long recognised resistance to lipid extracting solvents, ether, acetone and butanol, suggests that the virus contains no lipid in its outer structure and as the viruses of influenza and vaccinia inactivated by S.D.S. contain lipid there may be a general correlation between susceptibility to solvents and to detergents whether natural or synthetic.

Infective Ribonucleic Acid Preparations from Tissues and Cell Cultures infected with the Virus of Foot-and-Mouth Disease. It has been shown that phenol extraction of guinea-pig pads and pig kidney cell cultures infected with the virus of foot-and-mouth disease yields material capable of infecting mice and tissue cultures. Apparently complete virus can be recovered from animals and cultures infected with this material and the recovered virus exhibits the same pathogenic and cytopathogenic properties and is of the same immunological type as the original virus, as confirmed by serum neutralisation and complement fixation tests. The infective material is probably ribonucleic acid (RNA) since its infectivity is destroyed by minute amounts of ribonuclease although the infectivity of the intact virus is unaffected by this treatment. The infectivity of the RNA is not affected by immune globulins prepared from antiviral serum whereas the titre of virus suspensions is reduced. In view of the possibility that intact virus may be carried undisrupted through the phenol extraction process all the preparations of RNA have been checked by the addition of 1:10 volume of normal guinea-pig serum or ox serum. On no occasion has infectivity been detected in RNA preparations treated in this way. Furthermore most of the RNA preparations have been found to be non-infective when inoculated intraperitoneally into 7-day-old mice. As the virus is highly infective by this route considerable breakdown of the RNA must occur in the peritoneal cavity. If the peritoneal fluid of a 7-day-old mouse is added to infective RNA preparations, the infectivity is destroyed whereas the infectivity of virus preparations was unaffected by this treatment.

Whereas the virus is highly infectious when inoculated intraperitoneally or intramuscularly, the RNA is usually infective only intramuscularly. In this work the virus has been inoculated intraperitoneally and the RNA by the intramuscular route. Both the virus and the RNA can be titrated in pig kidney cultures. Virus suspensions have been fractionated by ultracentrifugation or by chromatography on DEAE-cellulose. Infective RNA could be obtained from those fractions which contained more than $10^{4.5}$ ID₅₀/ml. of infective virus. On the other hand when pig kidney cells in the latent period following infection with the virus were extracted with phenol, the ribonucleic acid was infective although at this time the cells contained only a trace of complete virus.

The multiplicity of immunological types of the virus of foot-and-mouth disease is a complicating factor in immunisation procedures. The significance of these studies in providing a new approach to this problem of lack of antigenic homogeneity is apparent.

Fractionation of the Virus of Foot-and-Mouth Disease by Chromatography on DEAE-cellulose. Crude suspensions of the virus of foot-and-mouth disease have been separated into two fractions by chromatography on DEAE-cellulose. One

fraction fixes complement with homotypic antiserum, has low infectivity and is identical with the 7 m μ component of the virus. The other fraction also fixes complement but is highly infective and is identical with the 20 m μ component of the virus. Recovery is quantitative. The method should be of considerable use for the removal from virus suspensions of gross amounts of accompanying protein impurities. Preliminary experiments have indicated that the method is likely to be useful for the concentration of large volumes of low virus titre fluids.

VACCINES AND VACCINATION

Inactivated Vaccines (tongue epithelium). There has been continued development of large scale virus culture and study of the factors involved in production of such virus of sufficiently high titre and large volume for the preparation of inactivated virus vaccines. Work has also been proceeding on the problems of large scale vaccine production. Considerable difficulties were encountered in arranging for an adequate supply of tongue tissue. These have now been overcome and 4 large batches of vaccine 600, 2,000, 2,000 and 2,400 titres have been prepared. Two of these have been submitted to stringent tests in cattle for safety and potency and have proved satisfactory. Two strains of different type were used for these vaccines. It is proposed in the first instance to work through the types to a point when a vaccine has been prepared from at least one strain of each of the seven types, and tested for safety and potency.

Inactivated Vaccines (kidney). Work is proceeding also using pig kidney cultures as a source of virus for vaccine production. Experiments in guinea-pig provided information on the optimal conditions for infecting cultures and harvesting virus for vaccine production. Tests comparing two inactivating agents have been made in cattle, mice and in culture. Some experiments in cattle have been done and further experiments are in progress with vaccines prepared from pig kidney culture virus.

Live Vaccines (modified strains). A considerable amount of work, which is on a long term basis, has been done and is continuing on modifying strains of virus, leading to a reduction of infectivity for cattle (production of visceral lesions), by passage in baby mice and/or adult mice and/or eggs and on the testing of the immunising properties of such strains for cattle. There are now a number of lines of modified virus. It is not proposed to make detailed reference to this work at present.

Tissue Culture. It is not proposed in this report to make detailed reference to the considerable advances in work on culture of the virus of foot-and-mouth disease and on the exploitation of tissue culture methods in different studies. Special reference may however be made to progress on the studies of the latent period of virus growth. Two different methods have been employed in these studies, one based on the instability of the virus at low pH and the other on a demonstrated temperature blocking effect on an appropriate virus cell system. In both cases sodium dodecyl sulphate has been used for extracting virus from cells.

It has been shown that the virus of foot-and-mouth disease becomes non-infective on entering the cell. An estimate of the rate at which virus enters the cell and becomes non-infective can also be made and further information obtained on the succeeding stages of virus multiplication.

ANIMAL DISEASES RESEARCH ASSOCIATION

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Director: John T. Stamp, D.Sc., M.R.C.V.S., F.R.S.E.

MICROBIOLOGY

Head of Department: J. G. Brotherston,
F.R.C.V.S., Dip.Bact.

A. Foggie, B.Sc., Ph.D., M.R.C.V.S.

J. M. K. Mackay, M.R.C.V.S.

G. R. Smith, M.R.C.V.S., D.V.S.M., Dip.Bact.

BIOCHEMISTRY

Head of Department: E. J. Butler,
M.A., B.Sc., D.Phil., A.R.I.C.

A. C. Field, M.V.Sc., M.R.C.V.S.

PARASITOLOGY

Head of Department: J. A. Campbell,

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M. G. Christie, B.A.

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PATHOLOGY

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Head of Department: I. Zlotnik,

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P. A. L. Wight, B.Sc., M.R.C.V.S., D.V.S.M.

Routine Pathology

D. I. Nisbet, B.Sc., Ph.D., M.R.C.V.S.

PHYSICAL CHEMISTRY

D. L. Mould, Ph.D., B.Sc.

CLINICAL INVESTIGATION

C. C. Renwick, M.R.C.V.S., D.T.V.M.

Secretary: D. M. Cameron, A.C.I.S.

The principal work of the Institute is to investigate the etiological factors concerned with diseases of farm animals and to discover means of preventing such diseases.

The scientific and experimental staff of the Institute at 31st March, 1958 numbered twenty-eight.

CURRENT WORK

Microbiology. The Department of Microbiology is mainly concerned with Johne's disease of cattle and sheep, sheep pneumonia and scrapie.

Since vaccination appears to be the most promising method of controlling Johne's disease it would seem to be essential to develop some indirect method of assessing immune response as direct vaccine trials on cattle and sheep are expensive and slow. Considerable progress has been made in developing such methods using small laboratory animals and, on occasion, sheep.

Work on sheep pneumonia has given convincing evidence that the etiological agent is *Pasteurella haemolytica*. Since the organism has been adapted to mice it is now possible to assess readily the immune response to various vaccines. The cultural and pathogenic characteristics of the *Pasturella* group vary considerably.

Further work on scrapie disease of sheep confirms that the disease is transmissible in series to sheep by inoculation. The disease can also be transmitted after the inoculum has been heated at 99.5°C. for eight hours. A controlled breeding experiment has given results indicating that there is a high correlation in incidence of natural scrapie between parents and offspring.

Biochemistry. Studies on hypomagnesemia using balance experiments with sheep provide no evidence of the presence in pasture associated with lactation tetany of a factor which inhibits magnesium utilisation. For the same type of diet there is a positive correlation between the magnesium intake and the amount of magnesium excreted in the urine. When the type of diet is changed suddenly, e.g. from hay to fresh grass, there is an immediate depression in the urinary excretion of magnesium which persists for several days, even when the change involves a substantial increase in the intake of magnesium. This indicates that the change of diet experienced by cows when they are turned out to grass in the spring may play a part in causing the disease at this time.

Sheep of the same breed and age differ greatly in the efficiency with which they are able to utilise dietary magnesium. This finding may help to explain the wide variation in susceptibility to the disease shown by different members of the same herd or flock. Approximate figures have been calculated for the magnesium requirements of sheep from the results of these experiments.

An investigation of outbreaks of swayback in the field, carried out in conjunction with the Veterinary Department of the Edinburgh and East of Scotland College of Agriculture, has given further information regarding the biochemistry and pathology of the disease. The levels of copper in blood and liver of ewes and lambs concerned with the disease have been found to be generally lower than those reported by earlier workers; this is probably due to improvements of biochemical techniques. Equally low levels are however found in sheep on farms where swayback has not occurred and in experimental sheep fed on diets low in copper. This would suggest that a low copper status is not the only factor involved in the etiology of the disease.

Parasitology. In two series of field observations no significant difference has been found in the helminthological status as between set-stocked animals and those grazed on a rotation period of seven days.

The spring rise in the output of parasite eggs has been observed after parturition in continuously housed animals and the subsequent course of the infestation levels was related to the system of management and feeding employed. These levels remained higher in animals kept indoors on dry feed than in those kept out-of-doors on grass.

The ensheathed larval stage of *Haemonchus contortus* is found to overwinter out-of-doors with comparatively little mortality and this species may survive in varying proportions up to twelve months. *Nematodirus battus* also persists and remains infective for sheep in significant numbers for periods of over two years. The persistence of eggs of this species is so great that they can remain viable for over twelve months in the early morula stage at subliminal temperatures.

Serum precipitation tests indicate that antigen is produced by *H. contortus* between the 48th and 120th hour after infection, i.e. by the trophic (L4 and L5) stages. This is partially confirmed by the use of these stages in protection tests. Morphological examination has shown a marked effect due to host resistance on larval growth rates and metamorphosis—i.e. inhibition of larval development after the first parasitic ecdysis. From histological examination it was found that the parasitic larvae live in the paramucosal lumen, i.e. on the tissue surface and in the crypts below the mucous layer, and inhibition of development in resistant animals is evident at these sites. There is no evidence of tissue penetration or concurrent tissue reaction in either susceptible or resistant animals.

Preliminary attempts at culture *in vitro* have been encouraging, the stage being reached where sexual differentiation is apparent, i.e. beyond the second parasitic ecdysis.

ANIMAL PHYSIOLOGY AND NUTRITION

THE ROWETT RESEARCH INSTITUTE

Bucksburn, Aberdeenshire

Director: D. P. Cuthbertson, C.B.E., M.D., D.Sc., F.R.S.E.

Deputy Director: A. T. Phillipson, M.A., Ph.D., D.V.Sc.(Hon.), M.R.C.V.S., F.R.S.E.

PROTEIN AND LIPID CHEMISTRY

Head of Department: R. L. M. Synge,
B.A., Ph.D., F.R.I.C., F.R.S.

Proteins

E. I. McDougall, B.Sc., Ph.D., A.R.I.C.
J. L. Bailey, B.Sc., Ph.D., A.R.C.S., A.R.I.C.

Miss M. I. Chalmers, B.Sc., Ph.D.

F. J. Bealing, B.Sc., Ph.D.

Lipid Chemistry

G. A. Garton, B.Sc., Ph.D.

MICROBIOLOGY

Head of Department: P. N. Hobson,
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B. H. Howard, B.Sc., Ph.D., A.R.I.C.

ENZYMOLGY

Head of Department: G. A. Levvy,
Ph.D., D.Sc., F.R.I.C.

C. A. Marsh, B.Sc., Ph.D., A.R.C.S.

J. Conchie, B.Sc., Ph.D.

G. Halliwell, M.Sc., Ph.D.

PHYSIOLOGY

Head of Department: A. T. Phillipson,
M.A., Ph.D., D.V.Sc.(Hon.), M.R.C.V.S., F.R.S.E.

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J. D. Pullar, B.Sc., Ph.D.

A. Dobson, B.A., Ph.D.

R. W. Ash, B.Sc., B.Sc. (vet. sci.), M.R.C.V.S.

T. M. Sutherland, B.Sc., Ph.D.

Secretary: W. Middleton, N.D.A. *Librarian:* W. L. Simpson, M.A.

PATHOLOGY

Head of Department: J. J. Bullen,

Ph.D., M.R.C.V.S.

Helminthology

G. C. Hunter, B.Sc.

APPLIED BIOCHEMISTRY

Head of Department: J. Duckworth,

B.S.A., D.Sc., F.R.S.E.

J. Davidson, B.Sc., Ph.D., A.R.I.C.

Miss G. M. Ellinger, B.Sc., Ph.D., A.R.I.C.

R. Hill, B.Sc., Ph.D.

C. F. Mills, M.Sc., Ph.D., A.R.I.C.

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APPLIED NUTRITION

Head of Department: J. A. Crichton,
M.B.E., M.A., B.Sc. (Agric.)

I. A. M. Lucas, B.Sc. (Agric.), M.Sc.

J. L. Corbett, B.Sc. (Agric.), M.Agr.Sc.

T. R. Preston, B.Sc. (Agric.), Ph.D.

STATISTICS

Head of Department: A. W. Boyne, B.Sc.

I. McDonald, M.A.

DUTHIE EXPERIMENTAL STOCK FARM

W. Thomson

The work of the Institute is directed to an understanding of the energy and material requirements of animals of agricultural importance. A study is also made of the relationship of diet to metabolic disorders and other underlying causes of susceptibility to disease. On the basis of the new knowledge obtained and of researches elsewhere, exploration is made of the best systems of feeding livestock and of the influence of environment on their utilisation. Man's food requirements are also kept under review. The Commonwealth Bureau of Animal Nutrition is located at the Institute.

The scientific and experimental staff of the Institute at 31st March, 1958 numbered ninety.

CURRENT WORK

Protein and Lipid Chemistry. The work of this department covers both chemical and metabolic studies. Particular attention is being given to the relation of fat in the diet of the ruminant to the utilisation of protein, by metabolic experiments and lipid chemical and microbiological investigations.

Increasing attention is being given to the nitrogenous constituents of leaves, mainly of forage plants. Work done in previous years on non-protein forms of bound amino acids in Italian rye grass has now been published. This related mainly to acidic and non-ionic material extracted from the grass juice by phenol. An amphoteric fraction, also extracted into phenol, has now been freed from free amino acids by using, as suggested by Dr. S. G. Waley, a column of anion-exchange resin buffered at pH 8-9. Attempts to characterise this fraction have

shown it also to be a complicated mixture of substances which yield on hydrolysis a mixture of the same amino acids as the acidic material. It exhibits some divergences from the properties expected for a mixture of peptides. However, the methods used for its isolation should be generally applicable to the separation of peptides from free amino acids.

In an attempt to assess the metabolic role of these fractions (^{14}C)-L-valine has been administered to whole shoots of Italian rye grass. Good incorporation of the radioactive valine into protein resulted; there was negligible transfer of radioactivity to other amino acids. Valine therefore seems likely to be generally useful for study of protein synthesis in plants. As judged by the specific activity of incorporated radioactive valine residues, the fractions referred to above are probably neither intermediate in the synthesis nor in the catabolism of protein, but are derived from free valine by some independent process.

Some exploratory work has been done on plastid and cytoplasmic proteins and a start made on the study of leaf proteases. The Lipid Section continues with its work on Vitamin E metabolism in pigs and has started a study of the composition of blood lipids with special reference to the lactating cow.

Microbiology. The variations in rumen protozoa and bacteria in calves on different feeding regimes have been studied in order to try to determine the optimum ration for rapid development of an adult type of rumen population in early weaned calves. Studies have been made of the carbohydrate fermentations carried out by some rumen protozoa, and the degradation of hemicelluloses by mixed and pure cultures of rumen bacteria. Preliminary work has been done on the elucidation of the role of proteolytic bacteria in rumen digestion.

Enzymology. By employing a new colorimetric method for the estimation of cellulose, cell-free filtrates from *Myrothecium verrucaria* were found to attack phosphoric acid-treated cellulose rapidly, and native cellulose slowly. Butanol extracts of micro-organisms from the rumen liquor of sheep attacked neither of these substrates, but hydrolyzed cellophane and carboxymethylcellulose. Gluconolactone arrested hydrolysis of the latter at about the stage of the pentaose.

Work on mammalian glycosidases has been extended to β -galactosidase, which, like others that have been studied, is particularly active in the genital tract and is under endocrine control. β -N-Acetylglucosaminidase was inhibited by N-acetylglucosaminolactone, the 1:5- being more powerful than the 1:4-lactone.

Physiology. Further work on the mechanism of absorption of acetate has been carried out. A preliminary experiment on the effect of feeding young summer grass containing a high content of nitrogen and potassium to sheep shows that the rumen potential is increased. This is likely to have an effect on the movements of all charged ions that are passively absorbed from this organ. Grazing experiments with dairy cows on pastures receiving different manurial treatments have continued and show that the responses of cattle to such treatments vary considerably.

The sensitivity of the reticulum, rumen and oesophagus as judged by salivation and reticulum movements to various stimuli has been examined in conscious sheep and in anaesthetised sheep, and a number of responses have been examined in detail. This type of investigation is necessary to know what is possible but it is equally important to know the normal movements of the reticulum and rumen and the variations that occur with the activity of the animal. Collaborative work with the Plant Chemistry Division of the D.S.I.R. New Zealand, on the incidence of rumen and reticulum movements in cattle has been done and the main problem becomes that of attempting to understand the relation of the known reflexes to the usual course of events.

An examination of the miscellaneous buccal and pharyngeal glands of sheep shows that in electrolyte composition and reflex activity they jointly behave as parotid glands except that their mixed secretion contains considerable quantities of mucus. The secretions from the abomasum have been examined in detail and the contribution these secretions make to the total of water and electrolytes secreted in the alimentary tract has been estimated.

The physiological meaning of the act of rumination continues to be examined and much time has been spent in examining ways and means of estimating the passage of food and water from the rumen during ruminating and quiescent periods. A promising method has been developed.

The testing of the new experimental temperature controlled rooms has taken up time and has presented certain problems; the assembling of metabolism cages and other necessities has now been accomplished and experimental work on electrolyte balance can now start using adequate groups of sheep under well controlled conditions.

The best temperature at which to rear young pigs has now been determined and it proves to be about 25° C., for pigs from 8 to 20 lb. The optimum temperature is lower than the critical temperature for pigs of 8 to 10 lb. Humidity seems to have very little effect. The large calorimeter is now in the testing stage and opens up possibilities of work on adult pigs, sheep, goats or cattle up to 3 months. There are a number of problems waiting for the calorimeter to come into operation.

The work on the use of ammonia nitrogen by *Lactobacillus bifidus* has continued. Statistically controlled counts of bacteria using ammonia show that variation in concentration in relation to the food does occur in sheep. These experiments indicate that differential counts of bacteria in the sheep's rumen can be contemplated on a more ambitious scale. The work involved, however, is slow and laborious and needs considerable organisation.

In contrast with its effect upon acetate oxidation by particulate preparations, propionate does not markedly inhibit citrate production from acetate by soluble preparations of liver. The reason for the difference between the particulate and soluble systems is being investigated. Results obtained during the year have thrown doubt on much of the possible evidence for the formation of carbohydrate from fatty acids in animal tissues. Thus, three reported interconversions of succinate and acetate have been critically examined and in each case evidence has been provided that the results obtained can be readily explained by other than a direct succinate-acetate interconversion. The effect of butyrate upon the blood glucose level of insulinized sheep has been shown not to be due to a formation of glucose from butyrate; this technique does not appear to be a satisfactory one for determining whether a compound is gluconeogenic.

An isotopic method for measuring the rates of production of short-chain fatty acids in the sheep rumen *in situ* has been satisfactorily developed.

Director's Unit. In the Director's Unit work covers the changing composition of the digesta throughout the alimentary tract and the effect of trauma and other factors on the mucosa of the tract.

The absorption and excretion of ^{45}Ca and ^{89}Sr in sheep have been studied. Results indicate that when both nucleides are given orally 3-4 times as much ^{45}Ca as ^{89}Sr finds its way into the skeleton. The appearance of ^{89}Sr in the alimentary canal after its intravenous injection is rapid—4 per cent of the dose being present in the lumen within an hour. The nucleide is well distributed throughout the canal but most is found in the small intestine. 7-8 times as much ^{89}Sr as ^{45}Ca is excreted by the kidney after intravenous injection.

A study of the effect of vitamin deficiency on foetal development has begun.

Pathology. Normal sera can protect eggs against *Clostridium welchii* type A infections. A component in both normal and immune serum, other than antibody, is essential for the inhibiting effect. Progress has been made in the fractionation of toxic filtrates of *Cl. welchii* by zone electro-phoresis in columns.

Development of the successful formolised vaccine against *Corynebacterium pyogenes* continues.

Systemic growth-effects associated with injury have been demonstrated in transplanted tissues.

Studies on host-helminth relationships have led to the cultivation of *Nippostrongylus* larvae *in vitro*.

Applied Biochemistry. Studies of dietary components influencing the availability of ingested copper to the animal are proceeding. Attention is at present being paid to mechanisms underlying the antagonistic effect of dietary molybdenum and sulphate on copper utilisation by the ruminant.

Since it is known that in the non-ruminant, dietary sulphate prevents the development of molybdenum toxicosis, and further, that in the ruminant dietary sulphate is a precursor of sulphide in the rumen, the effect of simultaneously feeding molybdenum and sulphide to the rat has been investigated. Our earlier suggestions that such treatment rapidly induces a copper deficiency in the rat have been confirmed.

In work with the sheep sulphide production in the rumen and its influence on the solubility of copper and the electrophoretic mobility of soluble organic copper complexes are being examined. Peak sulphide production in the rumen is observed 3-4 hours after feeding a grass cube diet and preliminary results suggest an inverse relationship between sulphide production and copper solubility. These studies are to be extended to animals receiving supplementary molybdenum.

In April 1954 an unusual mouth condition associated with very poorly mineralised mandibles and a general disturbance of bone metabolism among ewe hogs at Glensauigh Farm was investigated. Recently, observations on the permanent dentition of these animals have revealed a high incidence of enamel hypoplasia of incisor teeth and in some animals the molar teeth were worn in an unusual manner. These dental abnormalities were apparently related to the disturbance in mineral metabolism which occurred when the teeth were developing in the young animal.

The degree of grinding of oats, incorporated in a diet for pigs, has no appreciable effect on their digestibility, or on the rate of growth of the animals or on food conversion efficiency. Pigs fed on coarsely ground oats had a lower killing-out percentage than pigs fed on medium or finely ground oat rations.

When feeding laying hens housed under intensive conditions of management, the fortification of groundnut meal with methionine had little or no effect on the supplementary value of the groundnut meal protein in cereal-based rations.

When feeding table poultry the utilization of dietary metabolizable energy from wheat and maize rations is greater than from barley and oat rations. Under prevailing market conditions with wheat selling at prices only slightly above those for barley and oats, high wheat rations are most economical.

The collaborative trials aimed at developing rapid laboratory tests for accurately assessing the supplementary value of protein concentrates, in practical pig and poultry rations, have continued. The "available lysine" method has yielded results for animal by-products correlating well with results obtained in chick tests using the "Gross Protein Value" technique. Modifications to adapt it for use with plant by-products are being examined. Other tests are being studied, some of which show promise.

A study of the use of 4-amino antipyrine for the *in vivo* determination of body water in poultry has shown that the rate of removal of this substance from plasma water is rapid. Because of this rapid removal the method did not yield results of useful accuracy.

Applied Nutrition. The Applied Nutrition Department is investigating the feeding of concentrates and roughage to young calves, the usefulness of implanted hormones and food supplements to lambs, the maintenance requirements of grazing cattle, the prediction of herbage digestibility and the passage of reference substances through the bovine gut. Recent results indicate that underfeeding dairy heifers from birth to first calving does not affect yield or percentage SNF but does affect percentage butter fat, that the early weaning of pigs may reduce carcass quality and that high plane feeding for lactating sows is uneconomical.

Statistics. Apart from the development of new designs and techniques for animal experiments, anthropometric and energy expenditure surveys are being made on man.

Duthie Experimental Stock Farm. On the Duthie Experimental Stock Farm the nutrition of the breeding ewe during pregnancy and lactation is being studied in relation to lamb production. The nutritive value of heather on the hill for grazing sheep seems limited to material of not more than four years growth, the younger material being preferentially selected.

A.R.C. INSTITUTE OF ANIMAL PHYSIOLOGY Babraham, Cambridge

Director: I. de Burgh Daly, M.A., M.D., F.R.C.P., F.R.S.

Deputy Director: Sir Alan N. Drury, C.B.E., M.A., M.D., F.R.C.P., F.R.S.

PHYSIOLOGY

Head of Department: I. de Burgh Daly,
M.A., M.D., F.R.C.P., F.R.S.

K. J. Hill, M.V.Sc., M.R.C.V.S.

J. L. Linzell, B.Sc., Ph.D., M.R.C.V.S.

L. E. Mount, M.D., C.M., M.B., B.S.

J. S. Perry, B.Sc., Ph.D.

I. W. Rowlands, M.Sc., Ph.D.

Miss C. O. Hebb, M.A., Ph.D.

G. Fegler, M.D.

J. Bligh, B.Sc., Ph.D.

BIOCHEMISTRY

Head of Department: Sir Rudolph Peters,
M.C., M.D., F.R.C.P., F.R.S.

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V. P. Whittaker, M.A., D.Phil.

D. B. Lindsay, B.A., B.Sc., D.Phil.

P. F. V. Ward, B.A., B.Sc., Ph.D.

D. Lewis, M.A., M.Sc., Ph.D., A.R.I.C.

E. F. Annison, B.Sc., Ph.D., A.R.I.C.

EXPERIMENTAL PATHOLOGY

Head of Department: Sir Alan N. Drury,
C.B.E., M.A., M.D., F.R.C.P., F.R.S.

A. D. Bangham, M.B., B.S., M.R.C.S., L.R.C.P.

B. Cinader, B.Sc., Ph.D.

E. J. H. Ford, M.V.Sc., M.R.C.V.S.

A. E. Pierce, M.Sc., Ph.D., F.R.C.V.S., D.V.S.M.

D. C. Hardwick, B.Sc., Ph.D.

Secretary: E. Norris, B.Comm.

Librarian: D. W. Butcher, M.A.

Farm Manager: T. M. Fulton

The Institute is devoted to the study of the physiology of normal animals with especial emphasis on sheep, goats, cattle and pigs.

On 31st March, 1958, the scientific and experimental staff numbered fifty-eight.

CURRENT WORK

Physiology. Investigations on ruminant animals have had a prominent place in the programme of this Department. Studies on sheep have included the effect of ambient temperature change with an analysis of the receptors

which initiate panting in response to high temperature; and, in continuation of earlier work, the regulation of the digestive secretions, the functional anatomy of the autonomic nervous system, cerebral representation of autonomic pathways and the determination in unanaesthetized animals of normal values for blood pressure, heart rate and cardiac output. Further progress has been made in studying total blood flow through the body, and the flow through individual organs in both unanaesthetized and anaesthetized animals. Studies of artificial insemination by intraperitoneal injection have also been carried out on the sheep and the rabbit in conjunction with other work on the control of the life span of the *corpus luteum*. In continuing studies on lactation the innervation of the goat and sheep udder has been mapped out and there is encouraging progress in getting conditions under which the artificially perfused udder will produce milk (work done in collaboration with the Department of Experimental Pathology). On pigs further work is being done in connection with prenatal mortality, while the metabolism in newborn pigs has been investigated for the environmental temperature range of 3–38°C. Neurochemical studies of demyelination and degeneration of nerves have been continued.

Biochemistry. Steady progress has been made in all the work reported last year. In especial, it may be mentioned that bull semen has behaved to labelling with radioactive isotopes essentially as ram semen. Studies on phospholipid metabolism have extended further our knowledge of phospholipases A and B, and in collaboration with the pathology department, have shown that surface phenomena are involved in this enzyme action; extensions to a study of such enzymes in the rumen are in progress. A technique for measuring rates of utilisation of radioactive acetate has been devised. Some advances have been made in the culture of the rumen protozoa which have been now induced to divide *in vitro*. Work is continuing in the field of fluorine derivatives. Several species of *Dichapetalum* from the Belgian Congo and East Africa have proved non-toxic; but there may be interesting applications for the fluorofatty acid.

Experimental Pathology. The development of tolerance to purified proteins in sheep and goats has been studied in further detail. A natural antibody to starch has been discovered in these animals and its zoological distribution investigated. Work on the natural haemolysins in sheep blood, their seasonal variation and their influence on cell compatibility has continued. The absorption of proteins from the gut of newborn calves has been studied, with special reference to the excretion of some of these proteins in the urine. The enzymes and stainable fat in biopsy specimens of the livers of cattle and sheep have been studied. A micro-electrophoresis apparatus has been constructed and used to study the chemistry of blood corpuscles and the part played by liquids in the enzymic hydrolysis of fatty acids from lecithin.

A.R.C. UNIT OF EMBRYOLOGY

Department of Zoology, University College of North Wales, Bangor, Caerns.

Honorary Director: Professor F. W. Rogers Brambell, B.A., D.Sc., F.R.S.
(Professor of Zoology, University College of North Wales)

Senior Scientific Staff:

W. A. Hemmings, B.A. R. Halliday, B.Sc., Ph.D.

The Unit has been concerned principally with the way in which antibodies produced by the mother are transmitted to the young animal either before or after birth, conferring upon it passive immunity to disease.

On 31st March, 1958, the scientific and experimental staff of the Unit numbered four.

CURRENT WORK

During the year under review work has been continued on the transmission of immunity before birth to the foetal rabbit and after birth to the suckling rat and mouse. The method of transport across the maternal/foetal barrier in the rabbit has been studied by injection of antitoxin and of serum proteins labelled with radioactive iodine, either into the uterine cavity, on the maternal side of the barrier, or directly into the foetal circulation, on the foetal side of the barrier.

The transmission of immunity across the gut of the young rat has been investigated by the administration of antibodies or isotopically labelled serum proteins by stomach tube and their identification subsequently in the circulation. Satisfactory progress has been made towards interpreting the mechanism of transmission across the gut wall. Administration of certain corticosterones to the young rat has been shown to produce changes in the gut which result in premature termination of its ability to transmit antibodies.

The transmission of immunity in the young mouse has been studied in relation to the experimental production of haemolytic disease. The syndrome in this animal appears to result primarily from haemagglutination, rather than from haemolysis.

A.R.C. UNIT OF MICROBIOLOGY

Department of Microbiology, The University, Sheffield

Honorary Director: S. R. Elsdon, B.A., Ph.D.

(Senior Lecturer in Microbiology, Sheffield University)

Senior Scientific Officer: J. L. Peel, B.A., Ph.D.

A study has been made of the effect of aeration and growth rate on the cytochrome content of the strict aerobe *Pseudomonas fluorescens*. The organism was grown in the continuous culture apparatus mentioned in last year's report. Aeration was controlled by the rate of air flow through the apparatus. The principal finding was that organisms when grown under conditions where oxygen supply limited growth, contained more haem pigments than those grown under conditions of optimum aeration. The total haem pigment of the cells was inversely proportional to the degree of aeration.

Measurements have been made of the growth yields ($\mu\text{g cells}/\mu\text{mole energy source}$) of *Saccharomyces cerevisiae*, *Streptococcus faecalis*, and *Propionibacterium pentosaceum* grown under anaerobic conditions. In all cases growth was proportional to the amount of the energy source added to the medium. *S. cerevisiae* and *Strep. faecalis* gave identical growth yields on glucose. In these two organisms it is possible to calculate the amount of adenosine triphosphate (ATP) formed and to express growth as a function of ATP. The yield of cells per mole ATP was constant and independent of the substrate. This type of experiment offers a new approach to the study of the energetics of growth, and this work is continuing. In the case of *P. pentosaceum* the ATP yields are not known and hence it is impossible at present to see whether in this organism also, growth is proportional to the ATP produced. The yield of cells from glucose was found to be about double that of *S. cerevisiae* and *Strep. faecalis*.

The work on the metabolism of the rumen organism LC is being continued. Studies have been made of the fermentation of lactate by both washed cells and cell free extracts. Indirect evidence has been obtained that acrylate in an active form (possibly acrylyl co-enzyme A) is an intermediate in the fermentation; a coupled oxido-reduction reaction between lactate and acrylate yielding pyruvate and propionate, has been studied in some detail.

The co-factor required for the oxidation of pyruvate by extracts of LC has been isolated and found to be acetyl co-enzyme A. Unfortunately, the assay procedure used for the co-factor was such that acetyl co-enzyme A could not be replaced by unacetylated co-enzyme A; when the assay procedure was modified, however, co-enzyme A was also active in the system. This was disappointing since a considerable effort was put into the isolation of this co-factor.

Work has continued on the green sulphur bacteria, and it has been found that these photo-synthetic organisms form phosphoglyceric acid in the early stages of the light reaction. Investigation is proceeding into the photo-metabolism of organic components by *Rhodospirillum rubrum*, and a study is being made of the early stages of the metabolism of propionate. Using 2-¹⁴C-propionate, it has been found that in the light, a number of intracellular compounds become labelled after 10 seconds exposure to the tracer; chief amongst these are succinate and fumarate, both of which have been isolated and are at present being degraded.

DAIRYING

THE NATIONAL INSTITUTE FOR RESEARCH IN DAIRYING

Shinfield, Reading, Berks.

Director: Professor H. D. Kay, C.B.E., D.Sc., Ph.D., F.R.S.

Deputy Director: A. T. R. Mattick, B.Sc., Ph.D., M.I.Biol.

DAIRY HUSBANDRY

Head of Department: A. S. Foot, M.Sc.

R. Braude, Ph.D., D.Sc., Dipl.Agrt.

P. A. Clough, B.Sc.

F. H. Dodd, B.Sc., Ph.D.

C. Line, B.Sc.

K. G. Mitchell, B.Sc., Ph.D., N.D.A.

J. C. Murdoch, B.Sc., Ph.D.

J. Oliver, B.Sc., Ph.D.

FEEDING AND METABOLISM

Head of Department: S. Bartlett,

M.C., B.Sc., Ph.D., N.D.D.

C. C. Balch, B.Sc., Ph.D.

G. S. Pope, B.Sc., D.Phil., A.R.I.C.

J. H. B. Roy, M.A., Dip.Agric., Ph.D.

PHYSIOLOGY

Head of Department: S. J. Folley,

Ph.D., D.Sc., F.R.S.

G. K. Benson, B.Sc.

A. T. Cowie, B.Sc., Ph.D., M.R.C.V.S.

H. Gutfreund, Ph.D.

Miss M. L. McNaught (Mrs. Moore),
B.Sc., Ph.D.

BACTERIOLOGY

Head of Department: A. T. R. Mattick,

B.Sc., Ph.D., M.I.Biol.

N. J. Berridge, Ph.D., D.Sc.

C. A. E. Briggs, Ph.D., M.R.C.V.S.

G. C. Cheeseman, B.Sc., Dip.Bact., Ph.D.

L. F. L. Clegg, B.S.A., D.I.C., Ph.D., D.Sc.

Miss C. M. Cousins, B.Sc.

Miss E. I. Garvie, B.Sc., Ph.D., N.D.D.

L. A. Mabbitt, B.Sc., Ph.D.

F. K. Neave, B.S.A.

Miss M. E. Sharpe, B.Sc., Ph.D.

D. J. Williams, M.Sc.

CHEMISTRY

Head of Department: S. J. Rowland,

B.Sc., Ph.D., F.R.I.C.

R. Aschaffenburg, Ph.D.

M. J. Head, B.Sc., Ph.D., A.R.I.C.

R. L. J. Lyster, M.A., Ph.D.

J. A. F. Rook, B.Sc., Ph.D., A.R.I.C.

Secretary: H. F. Burgess, M.B.E., A.C.I.S. *Librarian:* Miss D. Knight, B.A., F.L.A., Dip.Lib.

The research in the Institute falls into two broad groups:—

(a) technical problems of milk production and utilization,

(b) the fundamental research required for the solution of these problems
which also leads to advances in production and utilization.

At 31st March, 1958, the scientific and experimental staff of the Institute numbered ninety-eight.

CURRENT WORK

Dairy Husbandry. Cinéradiographic methods have been used to measure the precise movement of the milking machine teat cup liner and the movement of milk out of the udder in relation to the pulsation cycle.

PHYSICS

Head of Department: G. W. Scott Blair,

M.A., Ph.D., D.Sc., F.R.I.C., F.Inst.P.

F. A. Glover, B.Sc., A.Inst.P.

J. D. S. Goulden, B.Sc., Ph.D.

L. W. Phipps, B.Sc., A.R.C.S., A.Inst.P.

J. H. Prentice, B.Sc., A.Inst.P.

ENGINEERING

Head of Department: H. S. Hall, B.Sc.

R. T. Budd, B.Sc.

H. Burton, B.Eng., M.Sc., A.M.I.E.E.

J. Hutchinson, B.Sc., A.I.Mech.E.

S. F. Suffolk, B.Sc.

C. C. Thiel, B.Sc., Ph.D.

NUTRITION

Head of Department: S. K. Kon,

Ph.D., D.Sc., F.R.I.C.

Miss M. E. Coates (Mrs. Goodwin),
F.P.S., Ph.D.

J. E. Ford, B.Sc., Ph.D.

Miss M. E. Gregory,

M.Sc.Tech., Ph.D., A.R.I.C.

Miss K. M. Henry, B.Sc., Ph.D.,

D.Sc., A.R.C.S.I., F.R.I.C.

E. S. Holdsworth, Ph.D., F.R.I.C.

J. W. G. Porter, M.A., Ph.D.

S. Y. Thompson, Ph.D., D.Sc.

ISOTOPES

Head of Section: R. F. Glascock, B.Sc., Ph.D.

STATISTICS

Head of Section: C. P. Cox, M.A., F.S.S.

DIRECTOR'S LABORATORY

R. H. Smith, B.Sc., Ph.D.

LIAISON UNIT

W. G. Wearmouth, B.Sc., Ph.D.,

A.R.I.C., F.Inst.P.

EXPERIMENTAL DAIRY

Miss H. R. Chapman, N.D.D.

In grazing experiments the great importance of stocking rate and relatively small importance of the method of controlling the grazing in the output of milk per acre has been demonstrated on grassland yielding about 1,000 gallons of milk per acre annually.

Using cabins in which the temperature and humidity were kept constant, it was observed that fattening pigs kept continuously in the dark, or continuously in artificial light, were in no way adversely affected when compared with pigs kept in daylight during the normal hours.

Feeding and Metabolism. For the new-born calf heat-treated milks, which appear to be nearly identical in composition, have given highly significant differences in performance.

In experiments on the requirements of young dairy stock and milking cows and the value of different foods, it has been shown that the proportion of hay included in the diet during the period between weaning and first calving, did not influence the subsequent ability to consume or digest hay or mixed diets.

Physiology. Cinéradiographic studies, in collaboration with the Nuffield Institute for Medical Research, on the mechanics of suckling have disproved the popular belief that the suckling sucks. The milk is in fact obtained by pinching off the neck of the teat between tongue and palate, a stripping action of the tongue then displaces the milk from the teat sinus into the back of the mouth.

Bacteriology. It has been shown that cud may well replace rumen material for the bacteriological examination of rumen contents of intact animals.

“Bitty cream” in milk pasteurized in the ordinary way is a great embarrassment to the trade. It has been shown that milk may be completely freed from living spores of the causative organisms by using modern V.H.T. apparatus.

Chemistry. Investigations have shown that the increase in the solids-not-fat content of milk when cows are grazing good spring pasture is due largely to an increase in the casein, β -lactoglobulin and α -lactalbumin, probably arising from a marked increase in the energy intake of the cow. The changes are consistent with those occurring when the plane of nutrition from winter rations is increased.

Physics. A new and rapid method, based on transmission measurements in the near infra-red and readily adaptable for continuous recording, has been devised for the quantitative assessment of homogenization of milk and shows good prospects of practical application.

Engineering. The use of radioactive tracers for measurement of holding time in H.T.S.T. heat exchangers offers no advantage over chemical tracers.

Calorimetric measurements on a milk tanker when new, and after 2 years' service, showed a 25 per cent deterioration in the efficiency of the thermal insulation.

A 4-point recorder milking machine has been modified to study methods of circulation cleaning using simple alkaline detergents.

Nutrition. The winter levels of vitamin A and carotene in bulk milk from depots throughout Great Britain have differed little from those in the survey done 15 years ago, despite changes in breed composition and feeding practice.

It has been established that the only carbohydrates that the new-born pig and calf utilize are glucose and lactose. Digestive enzymes capable of dealing with other carbohydrates appear in the pig but not in the calf within seven days of birth. The calf begins to utilize these carbohydrates only with the onset of rumination.

We have confirmed in rat tests that pastures and hays contain together with vitamin D a factor antagonistic to it.

Isotopes. It has been found that physiological doses (25 μ g.) of tritium-labelled hexoestrol administered, by subcutaneous injections in arachis oil solution, to immature female goats and lambs, accumulate for a short time in the uterus, vagina, ovaries and mammary glands. The maximum concentration in the blood and most organs occurs two hours after the injection, whereas that in the reproductive organs occurs five hours after the injection. Clearance of the oestrogen from all organs is very rapid and it is virtually all excreted after 24 hours. The principal routes of excretion are in the urine and faeces and hence there is also an accumulation for a short time in the kidney, urine and bile.

HANNAH DAIRY RESEARCH INSTITUTE

Kirkhill, Ayr

Director: J. A. B. Smith, D.Sc., Ph.D., F.R.I.C., F.R.S.E.

BACTERIOLOGY

Head of Department:
Constance Higginbottom,
M.Sc., Ph.D., Dip.Bact.

BIOCHEMISTRY

Head of Department: E. C. Owen,
B.A., D.Sc., Ph.D.
W. Manson, B.Sc., Ph.D.

GRASS AND DAIRY HUSBANDRY

Head of Department: M. E. Castle,
B.Sc., Ph.D., N.D.A., N.D.D.
D. Reid, B.Sc., M.S.

NUTRITION

Head of Department: K. L. Blaxter,
D.Sc., Ph.D., N.D.A.
D. G. Armstrong, B.Sc., Ph.D., A.R.I.C.

PATHOLOGY

Head of Department: P. S. Blackburn,
Ph.D., M.R.C.V.S.

PHYSIOLOGY

Head of Department: J. D. Findlay,
B.Sc., Ph.D.
W. Bianca, Dipl.Ing.Agr., Dr.Sc.Tech.
J. A. McLean, B.Sc.

TECHNICAL CHEMISTRY

Head of Department: R. Waite,
M.Sc., Ph.D., A.R.I.C.
J. C. D. White, B.Sc., Ph.D.
D. T. Davies, B.Sc., Ph.D.

Secretary: Miss M. M. Hughes *Librarian:* Miss E. T. Davidson

The Institute's main object is to study a wide variety of biological problems related to the production of milk, and also a number of problems associated with the handling of milk before and after it leaves the farm. The biological research work includes experiments on the management, conservation and utilization of grass and grass products and the production of other homegrown feedingstuffs. It includes also work on the nutrition of cattle from birth to maturity and throughout lactation, energy metabolism in ruminants, milk composition and factors that affect it, the effect of climate on the physiology of cattle, and the eradication or control of mastitis. Technical problems involve research work on the bacteriological quality of raw, pasteurized and sterilized milk and on the keeping quality and other properties of dried milk.

The scientific and experimental staff of the Institute at 31st March, 1958, numbered twenty-nine.

CURRENT WORK

Grass and Dairy Husbandry. During the past year work has continued on methods by which the Institute's dairy farm of 134 acres can be made to give maximum production with minimum use of imported feedingstuffs. Three main approaches to the problem have been followed, (i) replicated experiments with small grass plots to study methods by which the yield of herbage can be increased, the growing season lengthened and the quality of the herbage maintained or improved; (ii) experiments on the grazing of cattle to ensure that pasture is used with maximum efficiency; and (iii) winter feeding experiments

to determine to what extent the grass conservation products (hay, silage and dried grass) can replace imported concentrates without causing a decline in the yield and composition of the milk or in the health and well-being of the herd.

By applying the knowledge and experience that have been gained from this work over a number of years the efficiency and overall production of the farm have steadily increased. For example, the total milk production on the farm was 40,164 gallons in the year that ended in March, 1958 compared with 37,236 in the previous year and only about 19,000 in 1949. The milk production per acre rose from 201 gallons in 1949 to 266 gallons in 1956 and 291 gallons in 1957. The amount of utilized dry matter per acre of the farm's grasslands was calculated to be 39 cwt. in 1949 compared with 54 cwt. in both 1956 and 1957. These increases in total production and in the efficiency of production have been attained with but little use of feeds not grown on the farm itself.

Composition of grass. One of the nutritionally important fractions of grass is that known as the nitrogen-free extractives fraction, which makes up about 50 per cent of the grass dry matter. An extensive study has been made of the chemistry of this complex fraction. Valuable information has been obtained on its composition and how some of its many constituents vary with the stage of growth of the grass and with the growing season.

Nutrition. Much fundamental work is urgently needed on the energy requirements of ruminants for growth, maintenance, pregnancy and lactation, a subject which has been greatly neglected in the past forty years. During the past twelve months a building has been erected and equipped at the Institute for work on this important topic. With the equipment already available work has been done on the energy metabolism of sheep at different atmospheric temperatures.

In ruminants much of the energy-yielding substance of the diet is absorbed into the blood stream in the form of lower fatty acids. Basic work has therefore been done to study the heat production in sheep when acetic, propionic and butyric acids are introduced separately or in mixtures into the rumen.

Several respiration chambers for sheep and one that will accommodate a steer or a cow have been built and will soon be available for still more intensive studies in energy metabolism.

Physiology. The Institute's work on heat tolerance and acclimatization in cattle has continued, but during the period now under review much of the work of the staff concerned has been devoted to the building and equipping of the new climatic laboratory which is expected to be in full use towards the end of 1959. Respiratory activity and changes in the blood of calves under varying degrees of heat stress have been studied and work has been done also on acclimatization in calves. Histological research on bovine skin and on the muzzle has progressed well, and apparatus has been planned for measuring water transudation through the skin under a variety of climatic conditions.

Milk composition. Work has continued on the principal constituents of the non-fatty solids of milk and also on some of the vitamins it contains. A detailed study has been made of the influence of heredity, stage of lactation, season of year and diet on the levels of the main non-fatty constituents of milk. It is well known that with some dairy herds the milk frequently does not attain the presumptive minimum legal standard of 8.5 per cent for the level of non-fatty solids. The work done at the Institute on this subject is proving of great value in helping to elucidate this problem. It has been most helpful also in assisting the Scottish Milk Records Association to develop a scheme for recording the non-fatty solids content of milk on farms in addition to the fat-recording service which the Association has supplied for the past fifty years.

Mastitis. The research work on mastitis has included a study of the milks from a number of herds in the district which are regularly examined and in which every effort is made to eradicate, or at least control, not only the serious clinical forms of mastitis but also the sub-clinical forms which, although less obvious, may also cause considerable deterioration in the yield and composition of the milk. A study is being made also of the disease in some cows whose udders are later examined histologically *post mortem*, with the object of correlating the form and severity of the disease in the actively lactating animal with the amount and nature of the damage that is subsequently found in the milk secreting tissue.

POULTRY

A.R.C. POULTRY RESEARCH CENTRE King's Buildings, West Mains Road, Edinburgh, 9

Director: A. W. GREENWOOD, C.B.E., D.SC., Ph.D., F.R.S.E.

GENETICS

J. H. Sang, B.Sc., Ph.D.
Miss J. S. Blyth, B.Sc., Ph.D.
G. Tebb, B.Sc., Ph.D.
C. F. Pun, M.Sc., Ph.D.
A. G. Cock, M.A.

NUTRITION

W. Bolton, D.Sc., F.R.I.C., F.C.S., F.R.S.E.

PHYSIOLOGY

P. E. Lake, B.Sc., Ph.D.

PATHOLOGY

W. G. Siller, B.Sc., Dr. Vet. Med., M.R.C.V.S.

BIOCHEMISTRY

D. J. Bell, Sc.D., F.R.I.C., F.R.S.E.

ANIMAL BEHAVIOUR

D. G. M. Wood-Gush, B.Sc., Ph.D.

Secretary: A. B. Totty, B.A. *Librarian:* J. B. Coltherd, M.A.

The completion of building operations for the Centre's out-station at the Bush (The Edinburgh Centre of Rural Economy) has enabled a programme of research into problems affecting the turkey and broiler sections of the poultry industry to be initiated, and it is now in effective operation.

The scientific and experimental staff at the Centre numbered nineteen at the end of March, 1958.

CURRENT WORK

The following descriptions are concerned with selected new and completed lines of work, and do not include continuing long term investigations listed in the previous report.

Since broiler production is now a growing section of the Industry, two groups of breed crosses (White Leghorn $\times$ Rhode Island Red and Cornish $\times$ Light Sussex) have been established to form the basis of a 4-way cross which will be used to test the merits of different selection and breeding procedures with respect to broiler characteristics.

The relative efficiency of food utilization of genetically different lines is being studied. The digestive abilities of young chicks is being compared with those of later stages, and an attempt is being made to modify the former by adding enzymic dietary supplements.

The biochemical changes associated with growth, ovulation, moulting and disease are being studied, particularly as they affect the composition of the blood which can readily be sampled from time to time. Special attention is being paid to some of the precursors of yolk and their relation to its formation and composition.

The study of avian nephritis continues and has been extended to include a more detailed investigation of visceral gout. In this connection, the uric acid metabolism of both normal and nephritic birds is being examined.

Since artificial insemination has immediate advantages for the breeding of turkeys, work on the development of a semen diluent suitable for the Broad Breasted Bronze breed is in progress.

Experiments have also started with the same breed on the effects of different light treatments during the growing period on subsequent egg production of turkey females.

A diluent for fowl sperm based on a partial chemical analysis of seminal fluid has already given promising results—72 per cent fertility during days 2–6 after a single insemination with semen stored for 24 hours and diluted. Further chemical analysis of semen is projected in order to improve this diluent.

In co-operation with the University of Maryland, and the Ministry of Agriculture, Fisheries and Food Laboratories at Lasswade, it was possible to demonstrate reasonable fertility from fowl sperm flown to Scotland from the United States.

A method for predicting the fertilizing power of cocks from a microscopical examination of semen is also under investigation.

The effects of heredity and environment on the sex drive of the cockerel are being studied, as also are the effects of very early experience of the chick on the subsequent development of its social behaviour.

A time and motion study of birds kept in pens has shown seasonal differences of behaviour and indicated possible deficiencies in design of pen furnishings and in husbandry practice, as well as raising numerous problems relevant to feeding and other aspects of behaviour. Investigations have commenced on the experimental analysis of some of these which seem particularly relevant to egg production.

OUTCOME OF RESEARCH

Various pathological derangements in birds from the flock have been investigated and their dependence on heritable factors indicated. The occurrence of defects in the interventricular septum in the fowl, comparable with the human "Hole in the Heart" has been fully described. Unlike man the fowl can develop a compensatory mechanism, and the condition is not necessarily fatal. The condition was found in 87 per cent of the birds from one particular inbred line.

Massive oestrogenization of fowls, particularly males, affords considerable protection against liver damage by toxic substances; also in those with chronic hepatitis of long duration it stimulates the growth of new healthy liver tissue.

Spontaneous glomerulonephritis in the fowl has been described for the first time. The aetiology of the syndrome is unknown, but there is no suggestion that it corresponds to "Pullet Disease". A liver clearance test can be used for early diagnosis of hormone-secreting tumours of the reproductive organs in both sexes. Four new cancer-inducing viruses have been isolated from field cases.

There was no evidence that treatment of male parents with stilboestrol affected the sex ratio of their progeny, but treated female parents produced a preponderance of female offspring. Chickens of both sexes continuously fed the synthetic oestrogen (dienoestrol diacetate) in the diet from hatching were delayed somewhat in reaching sexual maturity in both sexes, but the males remained fertile and the pullets' egg production was not unduly affected.

In hybrids, growth prior to hatching has been found to be due to maternal influences rather than the genetic constitution of the developing embryo. In a study of female behaviour no overall trend between fecundity and sexual receptivity could be detected. A large proportion of egg white protein was found to be absorbed via the yolk during the latter half of incubation.

The results of a study of food efficiency for egg production by pullets, and yearling hens, showed that the difference between high and low energy diets was in digestibility, and not in efficiency of utilization of digested food. For each age, egg production was the same, and the food cost per bird or per dozen eggs was also the same, if the rearing cost was included for the pullet year.

HOUGHTON POULTRY RESEARCH STATION

Houghton, Huntingdon

Director: R. F. GORDON, D.Sc., M.R.C.V.S.

Senior Scientific Staff:

PARASITOLOGY

C. Horton-Smith, Ph.D., D.I.C.

BACTERIOLOGY

E. G. Harry, B.Pharm., Ph.C., M.Sc.

NUTRITION AND BIOCHEMISTRY

L. G. Chubb, M.Sc., A.R.I.C.

HUSBANDRY

Miss D. M. Cooper, B.Sc.

CLINICAL AND DIAGNOSIS

C. C. Wannop, M.R.C.V.S.

The existing research programme of the Station has continued to be directed towards the control of infectious diseases of poultry, particularly those of maximum importance to the industry and which arise from the continuing trends towards intensive production, such as protozoal infections—coccidiosis and blackhead—and bacterial infections, particularly salmonellosis and fowl typhoid. Incubator and brooder house hygiene are being studied and investigations are being made into the effect of the nutritional plane of the bird on the course of certain infections.

On 31st March 1958 the scientific and experimental staff numbered eleven.

CURRENT WORK

The current work of the Station, which is described in detail in the second Annual Report to the Governing Body, can be summarised as follows:—

Bacteriology

- (a) The effect on embryonic and chick mortality of shell contamination with bacteria from the hen and its environment; the sources of extra-genital contamination of the shell and the relationship between such contamination and the development of undesirable changes in egg composition; the relative pathogenicity to the chick embryo of various types of bacteria normally encountered in different systems of poultry management.
- (b) The screening of shell disinfectants for their efficiency in the control of egg-borne diseases and the effect on hatchability of antibiotics and non-toxic bacteriostatic chemicals introduced into the egg by immersion in refrigerated solutions.
- (c) The nature and extent of bacterial contamination of the atmosphere in poultry houses and atmospheric disinfection with various types of aerosols.
- (d) Studies of the emergence of antibiotic-resistant strains of bacteria resulting from the continuous feeding of antibiotics, particularly with respect to the *coliform* and *Salmonella* groups.
- (e) A detailed investigation of the efficacy of two live attenuated vaccines for the control of fowl typhoid has been completed and a report submitted for publication. The vaccine known as 9R is now in production and available commercially to the poultry industry.

Parasitology

- (a) A study has been made of the comparative activity of different drugs on experimentally produced infections with three species of intestinal coccidia of the fowl.
- (b) Work is being continued to determine the potentiation of sulphonamides exerted by different pteridine compounds.
- (c) Four species of coccidia are being investigated from the point of view of their cyto-chemical nature.
- (d) Experiments are proceeding to test the activity *in vivo* of compounds which have already exhibited activity *in vitro* against *Histomonas meleagridis*.
- (e) Methods of estimating the numbers of coccidial cysts in faecal suspension have been examined statistically, and the results published.

Nutrition and Biochemistry. The influence of nutrition on *Salmonella* infections and histomoniasis is being examined. The effect of certain antimetabolites on the haematology of the chick, and on the growth and progress of certain transplantable lymphoid tumours has been studied. Serum proteins and amino-acid metabolism are being studied by means of filter paper electrophoresis and paper chromatography to see whether these techniques can, in this way, profitably be employed in avian pathology.

Clinical. Clinical and experimental investigations are being made into the pathology of Haemorrhagic Disease. This work involves haematological studies of field cases and attempts to reproduce the disease by the administration of certain coccidiostatic compounds in association with possible infective agents.

A clinical investigation has been carried out on the condition known as Roundheart Disease, and attempts made to correlate outbreaks with different environmental conditions and the presence of certain infective agents.

Avian Reproduction. Work has now been completed on the effects on reproduction of certain additives such as the amino-nitrothiazoles and the nitrofurans. A preliminary experiment was carried out to estimate the fertilising potential of fowl semen by various techniques. Further work was carried out on the effect of a glycine diluent on the fertilising capacity of cock semen. In collaboration with the Ministry of Agriculture's Experimental Husbandry Farm at Gleadthorpe, an investigation was made into the possible effects of heterospermic insemination in the fowl.

The expansion of the Station referred to in the report for year 1956-57 is nearing completion. It is hoped that the new laboratories will be ready for occupation early in the spring of 1959. Steps have been taken to establish a new Department of Virology and to design a programme of research on respiratory disease of the fowl with the object of improving methods for their rapid differential diagnosis.

AGRICULTURAL ENGINEERING

NATIONAL INSTITUTE OF AGRICULTURAL ENGINEERING Wrest Park, Silsoe, Bedfordshire

Director: W. H. Cashmore, C.B.E., B.A., N.D.A.

AGRICULTURAL MACHINERY TESTING

Head of Department: D. I. McLaren,
B.Sc. (Agric.), N.D.A.

P. Hebblethwaite, M.Sc. (Mich.S.U.),
B.Sc. (Agric.), N.D.A.

R. D. Richardson, B.Sc. (Eng.), A.M.I.Mech.E.

FIELD INVESTIGATION

Head of Department: F. S. Mitchell,
B.Sc. (Agric.)

R. E. Arnold, B.A. (Agric.)

G. Shepperson, B.Sc. Dip. Agric.

GRAIN DRYING

Head of Department: J. Woodforde,
M.I.E.E., A.M.I.Mech.E.

P. E. Berry, M.Sc., A.M.I.Mech.E., A.F.R.Ae.S.

M. G. R. Warner, M.A., A.M.I.E.E.

HORTICULTURAL ENGINEERING

Head of Section: F. H. Vanstone,
B.Sc., Ph.D., A.Inst.P.

A. G. M. Bean, M.A. (Eng.), A.M.I.Mech.E.

J. B. Byass, M.A.

R. J. Courshee, B.Sc. (Eng.)

J. S. Wolfe, B.A., B.Sc. (Eng.)

Secretary: J. W. Andrews, F.C.I.S. *Librarian:* Miss J. A. Midgley

INSTRUMENTATION

Head of Department: S. W. R. Cox,
B.Sc., A.Inst.P.

MECHANICAL ENGINEERING

Head of Department: H. J. Hamblin, B.A.

P. H. Bailey, B.Sc. (Eng.), A.K.C.

T. C. D. Manby, M.Sc. (Eng.)

H. J. Nation, B.Sc. (Eng.), A.M.I.Mech.E.

P. A. Taylor, B.Sc. (Eng.)

SOIL MECHANICS

Head of Department: J. C. Hawkins,
B.Sc. (Agric.), N.D.A.

E. R. Fountaine, B.A., B.Sc.

GLASSHOUSE RESEARCH

Head of Section: L. G. Morris,
B.Sc. (Eng.), A.F.R.Ae.S.

E. S. Trickett, B.Sc. (Eng.)

SURVEY

J. K. W. Slater, M.A., M.Sc.

The function of the Institute is research into and development of agricultural and horticultural machinery; it also operates a testing service which covers all classes of tractor and implement.

The scientific and experimental staff at the Institute on 31st March, 1958, numbered ninety-seven.

CURRENT WORK

Three pilot surveys into various aspects of potato growing have led to the designing of a major "Survey of Main Crop Potatoes," which will be carried out in 1958, in co-operation with the Statistical Department, Rothamsted and the Potato Marketing Board. Assistance is also being given to the Farm Buildings Unit of the Agricultural Research Council in carrying out the "Survey of existing Farm Buildings."

Investigations. A series of trials have been carried out on the drying of baled lucerne and seeds hay in a barn drier, to determine the optimum conditions for the efficient drying of hay in bales. Further work has been done on the transport of bales from the field to the drier. Investigations into the risks of damaging grain during harvesting have covered the behaviour of damaged grain when stored for short periods in an undried state and when dried and stored for long periods.

In attempts to reduce the ratio of clods to potatoes at the time of harvest, potatoes have been planted in beds of three or four rows to eliminate the influence of the tractor wheels.

Investigations into the mechanization of the spring cultivation of sugar beet have continued on similar lines to those of previous years.

Research and Development. Further work on soil physics has established a relationship between tine width and its rake angle and the draught and volume of soil disturbed. In the investigation into soil compaction, measurements have

been taken of the oxygen consumption of plant roots and of the soil in which they are growing.

Grain research has included a study of hygroscopic equilibria, the behaviour of wheat and barley under various drying conditions and the cooling of grain stored in bulk. An investigation into the mechanical processing of sugar beet seed has been added to the programme. Research into oscillating conveyor mechanisms has continued, and a study of auger conveyors has been started. The heat exchanger equipment developed for grain and hay drying and the improved grain cleaner have been installed at a Ministry of Agriculture Experimental Husbandry Farm for further trials.

In connection with the development of grain threshing with an endless belt, a novel method of separating grain from chaff has been evolved.

New development projects include a carrot topper and toolbar equipment for the cultivation and planting by the tie-ridge system. The latter is undergoing field trials under semi-arid conditions in East Africa.

A number of machines have passed the field trial stage and are now in the hands of manufacturers, where pre-production prototypes are being constructed. These include a potato harvester, a groundnut harvester and a jute ribboner. Arrangements have been made for the full scale production of a humane rabbit trap, developed in co-operation with the Ministry of Agriculture.

Apparatus and Equipment. Arrangements have been made for the soil grinder, developed at the request of the National Agricultural Advisory Service, and the drill for plant breeding experiments, built for the Plant Breeding Institute, to be manufactured and sold commercially.

A remote reading anemometer has been built for hop drying work and a mounted seed drill for cereal plots has been built for the National Institute of Agricultural Botany. Other instruments designed and constructed include a multiple pressure membrane apparatus for the study of soil moisture characteristics and a seed counter and seed density apparatus.

Horticulture. Development work on an experimental spraying machine has been completed; it embodies new airblast nozzles developed by the Institute with the object of providing improved performance in commercial orchards.

The equipment developed for the propagation of cuttings under intermittent mist has been simplified and put into commercial production. Another development has been the automatic supply of water to small beds of glasshouse crops by means of a modified soil-moisture tensiometer.

The Institute's Integrating Photometer has been taken up by a manufacturer and is being widely used by research workers. A "Thermometer Bottle" technique has been evolved for measuring spatial variations of temperature within glasshouses; the small temperature differences it measures have been found to be significant in the growth and yield of tomatoes.

A prototype cabinet for environment control has been designed and the light distribution under artificial light sources has been examined.

In co-operation with the National Institute for Research in Dairying, work has been started on the use of plastic film as a substitute for glass.

Testing Service. Routine tractor testing has continued actively and collaboration with the East African Testing Unit has led to work on methods of simulating high altitude operating conditions, and the assessing of diesel engine exhaust. Tractor hydrostatic transmissions are now being accepted for routine tests.

Tests of drying equipment have been extended to include hop driers.

The demand for routine testing of implements has been up to the full capacity of the staff available, and technical assistance has been given to the

East African Testing Unit in connection with their implement testing activities; these have included series tests of bush clearing equipment.

The Institute's Series Tests on spinning disc fertilizer distributors have been completed; the comparative results from this class of test are of considerable value to both farmers and manufacturers.

SCOTTISH STATION

Howden, Mid-Calder.

Director: W. J. West, B.A., Dip. Agric.

Senior Scientific Staff:

R. G. Clark, B.Sc. (Agric.), M.Sc. (Ag. Eng.)

G. Gilfillan, B.Sc. (Eng.), M.Sc.

I. M. Robertson, B.Sc., Ph.D.

Secretary: D. Warne

The Station participates in the Testing Scheme of the National Institute of Agricultural Engineering and studies problems of farm mechanisation related specifically to conditions in Scotland and in other similar areas of the United Kingdom.

The scientific and experimental staff of the Station at 31st March, 1958, numbered thirteen.

CURRENT WORK

Two large scale trials to ascertain the cost of the mechanical treatments necessary to bring vigorously growing bracken under control were concluded. A further trial was laid down to study the nature and frequency of mechanical treatments required to keep bracken under control.

Investigations into the spring cultivation of turnips grown on ridges included studies of the effects of fineness of tilth and consolidation on the germination of seed sown by precision and non-precision seeders and of the technique of down-the-row thinning. Special machines, giving accurate control of the working units, were developed for sowing and thinning.

The rate of drying of hay, put on to tripods and into field ricks after various lengths of time in the swath, was measured using continuous weight recorders. The information will be used to determine the type of structure most suitable for areas of high rainfall and suitable for mechanisation.

Field investigations into the technique of swath harvesting of oats and barley were continued. These included: (a) a comparison of the rate of drying of swathed and stooked corn; (b) the effect of weather conditions on the over-all ripening period of swathed material; (c) a comparative yield trial of direct combine harvesting, swathing and pickup harvesting and binding, stooking, stacking and threshing and (d) the effect of the size of swaths and their arrangement on the working speed of a combine harvester.

The survey of the operation of farm grain drying installations of the in-bin type, started in 1955 and continued in 1956, was completed in 1957. The survey indicated the problems that need further investigation.

Problems associated with the development of a complete potato harvester were studied. The damage to tubers caused by various types of harvesting equipment was measured and was compared with the greater damage resulting from careless handling during transport and storage. An assessment was made of the relative susceptibilities to damage of Kerr's Pink and Majestic potatoes grown on a wide range of soil types. Three aspects of the problem of securing a

clean sample of potatoes were examined. These were: (a) the relative importance of the factors affecting manual separation of potatoes from stones and clods on the picking belt of a complete harvester; (b) the possibility of devising mechanisms capable of differentiating between potatoes and other material; and (c) the effect of cultural practices on the presence of clods in the rows at harvest.

With the ultimate object of producing an improved potato sorter, an experimental spool-type machine was built and was used for an examination of the factors affecting the efficiency of grading of tubers of contrasting shapes.

A detailed report of the Station's work was published as a section of the Annual Report of the National Institute of Agricultural Engineering.

STATISTICS

A.R.C. UNIT OF STATISTICS

University of Aberdeen, Meston Walk, Old Aberdeen

Director: D. J. Finney, M.A., Sc.D., F.R.S., F.R.S.E.

Senior Scientific Officer: M. R. Sampford, M.A., D.Phil.

The purpose of the Unit is to make available for agricultural research in Scotland the kind of service provided for England and Wales by the Statistics Department of Rothamsted Experimental Station. This involves giving advice to Agricultural Colleges and Research Institutes on statistical aspects of the planning of research projects and on the analysis and interpretation of results. The Unit also undertakes investigations into statistical theory and methodology that are in any way related to the needs of agricultural research, including problems of theory that arise from questions submitted by staff of the other Institutes.

On 31st March, 1958 the graduate staff of the Unit numbered five in addition to the Director.

CURRENT WORK

The work of the Unit has continued to develop. Assistance to members of the staff of the Scottish Agricultural Colleges and of various research institutes now covers a wide range of problems.

The Survey of Fertilizer Practice in Scotland appears to be firmly established, and eighteen districts have been completed in the past three years. The value of this work is increasingly appreciated as comparisons between more districts become possible. Co-operation with the Grassland Committee of the Scottish Agricultural Improvement Council has continued, and a number of reports have been prepared on the basis of analyses made by the Unit. The completion of one stage of research on sugar-beet cultivation undertaken through the Scottish Sub-committee of the Sugar-beet Research and Education Committee led to the publication of a short paper on the spacing and methods of fertilizer application found most suitable under Scottish conditions. Assistance is being given to a joint committee of the Agricultural Research Council and the Medical Research Council in connection with a United Kingdom sample survey for the monitoring of strontium in milk. It is hoped that the scheme will enable a regular check on Sr90 content to be maintained in the ten zones into which the country has been divided; the sample is thought to be more representative than has ever been attempted elsewhere.

Research into the theory of selection, with particular reference to problems of selecting new crop varieties from large numbers of new seedlings, has been a

major activity. Interesting results under a number of contrasting assumptions are now being reached, and attempts are being made to assess the relative economic merits of different schemes of selection. Although this research is primarily theoretical, it is hoped that the broad indications will eventually prove of practical value.

A.R.C. STATISTICS GROUP
School of Agriculture, University of Cambridge

Officer-in-charge: R. C. Campbell, M.A., Ph.D.
(Lecturer in Agriculture (Statistics), University of Cambridge)

The Group was established as a separate entity in January, 1956, and is professionally responsible to Dr. Yates, Head of the Statistics Department at Rothamsted Experimental Station. Close contact is maintained both with the School of Agriculture and the Statistical Laboratory of the Faculty of Mathematics at Cambridge. The Group's local computing facilities are augmented by the use of the automatic calculator at Rothamsted.

The Group gives advice and assistance in the design and analysis of animal experiments. Most use of this service has been made locally by the Unit of Reproductive Physiology and Biochemistry, the Institute of Animal Physiology and the Houghton Poultry Research Station; one member of the Group specialises in work associated with these laboratories. In addition, the Group designs and analyses the Agricultural Research Council's Co-ordinated Experiments on pigs and is associated with experiments at the Council's Field Station at Compton. The other main subject dealt with is carcase quality of cattle and pigs; another member of the Group, who is on the Advisory Committee of the National Pig Progeny Testing Board, deals with this work.

RADIOBIOLOGY

A.R.C. RADIOBIOLOGICAL LABORATORY
Grove, Wantage, Berkshire

Director: R. Scott Russell, M.Sc., M.A., Ph.D.

Senior Scientific Staff:

E. R. Mercer, B.Sc. L. J. Middleton, B.Sc., Ph.D.

Secretary: Miss Y. D. Scott, B.A.

In August, 1957, it was decided that the investigation of the radiobiological contamination of biological materials, other than human tissues, would become the responsibility of the Agricultural Research Council. To implement this decision a Sub-Committee of the Joint M.R.C./A.R.C./D.C. Committee on the Biological Problems (Non-Medical) of Atomic Physics was set up to plan future monitoring work; the Sub-Committee is directly responsible to both Research Councils. The A.R.C. Radiobiological Laboratory was established to carry out the necessary investigations; experimental studies of the fate of fission products in both soils and plants, which had hitherto been conducted at the Council's Field Station at Compton and elsewhere, were transferred to the new Laboratory. The Laboratory has the dual tasks of determining the levels of radioactivity in agricultural produce in Great Britain which result from world-wide

fall-out and of studying the factors which affect the movement of fission products through the soil/plant chain. The two requirements are closely related since the present situation can be interpreted only if the underlying mechanisms are understood.

At the present time the long-term consequences of fall-out from nuclear weapon tests are receiving particular attention; the work of the Laboratory is, however, directed also to providing information necessary to ensure safety in agricultural areas surrounding nuclear reactors and to providing information necessary in the planning of Agricultural Civil Defence against the possibility of Nuclear Warfare.

Temporary accommodation for the Laboratory was made available by the Atomic Energy Authority at Grove Airfield, Wantage, Berks. In January, 1958, action was taken to organise facilities for the preparation of samples and for low-level radiochemical assay. The Council has now purchased the Letcombe Manor Estate, near Wantage, Berks to provide a permanent home for the Laboratory. It is hoped that this will be ready for occupation in 1960. Since the accommodation at Grove is sufficient to house only investigations of world-wide fall-out, experimental studies will continue to be accommodated at the Field Station, Compton, at the Department of Agriculture, University of Oxford, and at the M.R.C. Radiobiological Research Unit, Harwell, until the Laboratory is moved to Letcombe.

On 31st March, 1958, the scientific and experimental staff of the Laboratory numbered eleven.

CURRENT WORK

Plant Physiology and Soil Science. Plant physiological investigations have been directed primarily to the study of the interaction of strontium and calcium in absorption by roots and to the foliar absorption of carrier-free strontium-89 and caesium-137. Special apparatus has been designed to enable radioactive sprays to be applied in safety.

The fate of strontium-90 and caesium-137 is being studied in a range of representative soils contained in cylinders approximately 1 cubic yard in capacity. Absorption by test crops and the rate of penetration of both isotopes down the soil profile are being measured; these observations will be repeated for at least five years. The extent to which variations in root depth effect the absorption of strontium-89 from soil by different species is under investigation.

Detailed laboratory studies of the behaviour of fission products in the soil have been directed largely to the relationships between strontium and calcium.

The effects of ionising radiation on salt uptake are under investigation; *Chlorella* is the principal test plant.

Field Experiments with strontium-89. A series of six field experiments on representative soil types began in 1956. The experiments are located in various parts of Southern England; the majority of sites have been made available by the Ministry of Agriculture, Fisheries and Food. The object of the work is to determine the rate of absorption of radioactive strontium from soil under field conditions and to investigate the extent to which absorption can be reduced by the modification of agricultural practices.

Survey of strontium-90 from fall-out in human diet. The survey is divided into two sections: a "country-wide" survey, the object of which is to determine the mean exposure of the entire population in the United Kingdom, and a "special area" survey designed to estimate the exposure in localised areas where the extent to which fall-out is deposited, or biological factors, may cause the intake of strontium-90 to be higher than the average for the country. Since milk and milk products are the principal routes whereby strontium-90 now enters human

diet, the sampling of milk receives particular attention. Samples, representative of a day's production, are collected twice monthly from over 200 milk depots which between them handle some 40 per cent. of the total milk produced in the United Kingdom. The laborious nature of radiochemical assay makes it impossible to assay these samples individually and an elaborate bulking scheme has therefore been devised. The United Kingdom has been divided into ten zones in each of which the depots have been separated into two groups, each representative of half the milk sampled; the milk in each group is bulked in proportion to the through-put of the depots and assayed at six or twelve week intervals, depending on the importance of milk production in the zone. Flour, potatoes and green vegetables are also sampled, though in a less elaborate manner.

Six "special areas" have been selected (2 in England, 2 in Scotland, 1 in Wales, 1 in Northern Ireland) in localities where the deposition of strontium-90 is above the country-wide mean on account of high rainfall. Samples of milk and vegetables are obtained from individual farms, or groups of farms in these areas; animal bones are also sampled.

The sampling schemes were initiated in March, 1958. As the radio-chemical laboratory at Grove was not then ready to commence analytical work, arrangements were made for the Atomic Energy Authority to assay samples prepared by the Laboratory during the year 1958-1959.

Investigation of the deposition of strontium-90 from fall-out in soil, pastures and sheep bones. The object of this programme is to provide information on the rate of passage of strontium-90 through food chains and to assess the total deposition per unit area of land. Sampling schemes are in operation in 17 localities representative of a wide range of ecological and climatic conditions.

Accident at Windscale Works, October, 1957. In collaboration with the Atomic Energy Authority the Laboratory undertook investigations of the levels of strontium-89 and 90 in representative farms in the Windscale area.

STATE-AIDED AGRICULTURAL RESEARCH INSTITUTES

England and Wales

Rothamsted Experimental Station	...	Harpenden, Herts.
East Malling Research Station	...	Maidstone, Kent.
Grassland Research Institute	...	Hurley, Maidenhead, Berks.
Agricultural and Horticultural Research Station.		Long Ashton, Bristol.
National Vegetable Research Station	...	Wellesbourne, Warwick.
Welsh Plant Breeding Station	...	Plas Gogerddan, Aberystwyth.
John Innes Horticultural Institution	...	Bayfordbury, Hertford.
Glasshouse Crops Research Institute	...	Rustington, Littlehampton.
Research Institute of Plant Physiology		Imperial College of Science and Technology, London, S.W.7.
Plant Breeding Institute	...	Trumpington, Cambridge.
National Institute for Research in Dairying.		Shinfield, Reading, Berks.
Foot-and-Mouth Disease Research Institute (Animal Virus Diseases).		Pirbright, Woking, Surrey.
Houghton Poultry Research Station	...	Houghton, Huntingdon.
National Institute of Agricultural Engineering.		Wrest Park, Silsoe, Beds.

Wye College Hop Research Centre ... Ashford, Kent.

Scotland

Macaulay Institute for Soil Research	...	Craigiebuckler, Aberdeen.
Scottish Horticultural Research Institute		Mylnefield, Invergowrie, Dundee.
Scottish Plant Breeding Station	...	Pentlandfield, Roslin, Midlothian.
Rowett Research Institute	...	Bucksburn, Aberdeenshire.
Hannah Dairy Research Institute	...	Kirkhill, Ayr.
Animal Diseases Research Association		Moredun Institute, Gilmerton, Edinburgh.
National Institute of Agricultural Engineering Scottish Station.		Howden, Mid-Calder, Midlothian.
Hill Farming Research Organisation	...	48, Palmerston Place, Edinburgh, 12.

AGRICULTURAL RESEARCH COUNCIL INSTITUTES AND UNITS

Field Station	...	...	...	Compton, Newbury, Berks.
Animal Breeding Research Organisation	H.Q.:	6,	South Oswald Road, Edinburgh, 9.	
Institute of Animal Physiology	...	...	Babraham Hall, Babraham, Cambridge.	
Poultry Research Centre	...	...	King's Buildings, West Mains Road, Edinburgh, 9.	
Unit of Animal Genetics	...	...	Department of Animal Genetics, Univer- sity of Edinburgh, King's Buildings, West Mains Road, Edinburgh, 9.	
Unit of Biometrical Genetics	...	...	Department of Genetics, Birmingham University.	
Unit of Embryology	...	...	Department of Zoology, University Col- lege, Bangor.	
Unit of Experimental Agronomy	...	...	Department of Agriculture, Oxford University.	
Unit of Insect Physiology	...	...	Department of Zoology, Cambridge University.	
Unit of Microbiology	...	...	Department of Microbiology, Sheffield University.	
Unit of Plant Cell Physiology	...	...	Department of Agriculture, Oxford University.	
Unit of Plant Nutrition (Micro- Nutrients)			Long Ashton Research Station, Bristol.	
Radiobiological Laboratory	...	...	Grove, Wantage, Berks.	
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